The evolution of a low carbon domestic energy system

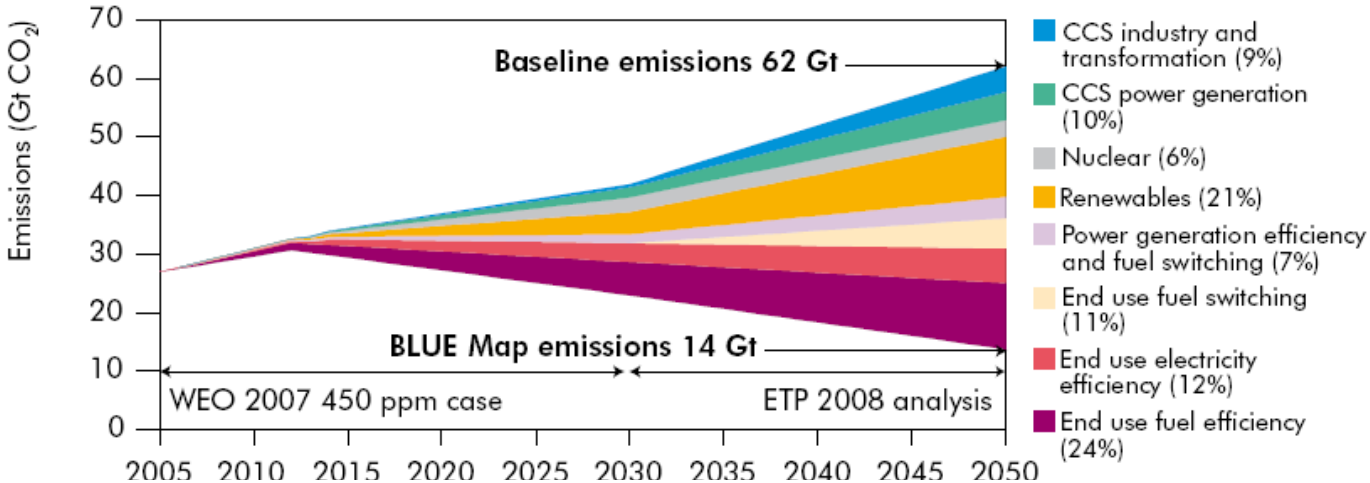
Tadj Oreszczyn and Robert Lowe
UCL Energy Institute
University College London

BUILDINGS AND CLIMATE CHANGE

Status, Challenges and Opportunities, UNEP 2007

- “Worldwide, 30-40% of all primary energy is used in buildings.” “In Europe, buildings account for 40-45% of energy consumption in society“
- “The building sector thus offers the largest single potential for energy efficiency in Europe: more than one-fifth of the present energy consumption and up to 45 million tonnes of CO2 per year could be saved by 2010 by applying more ambitious standards to new and existing buildings.”
- “On the global level, knowledge regarding the energy use of building stocks is still lagging be-hind”

Figure ES.2 ▶ Comparison of the *World Energy Outlook 2007* 450 ppm case and the BLUE Map scenario, 2005-2050



IEA Technologies Perspective 2008

Economic mitigation potential by sector in 2030

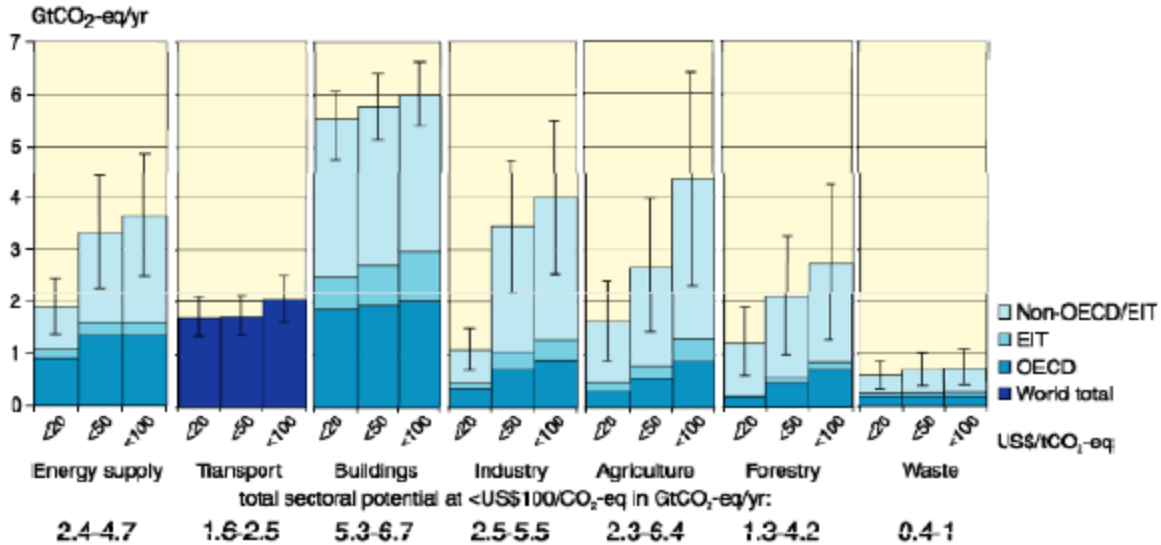
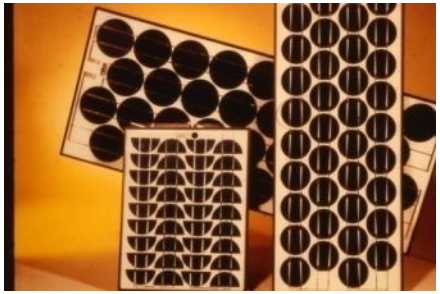
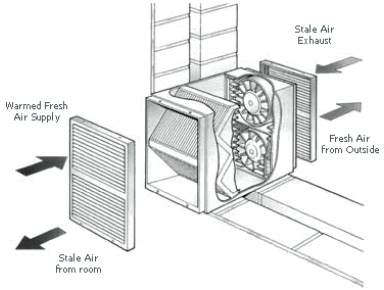


Figure 2. Estimated economic mitigation potential by sector in 2030 from bottom-up studies, compared to the respective baselines assumed in the sector assessments. The potentials do not include non-technical options such as lifestyle changes. Source: IPCC Climate Change 2007 Synthesis Report (IPCC 2007).

What are the options?





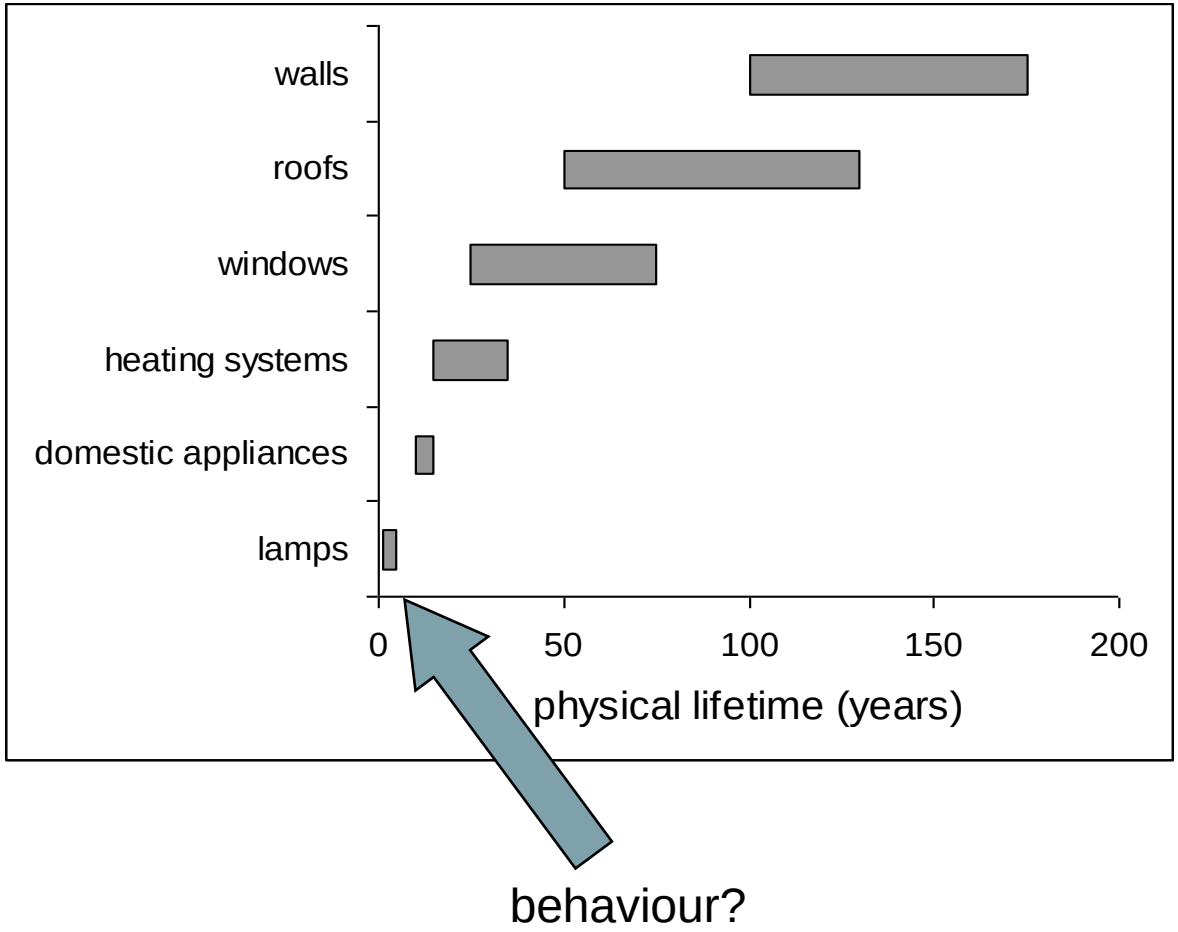
http://www.eco-hometec.co.uk/Ground%20Source%20Heat%20Pumps.htm

http://www.whispertech.co.nz/content/library/WTL026Brochure.pdf

Reducing heat loss

Efficient heating cooling and energy generation

wide range of sub-system characteristic times…



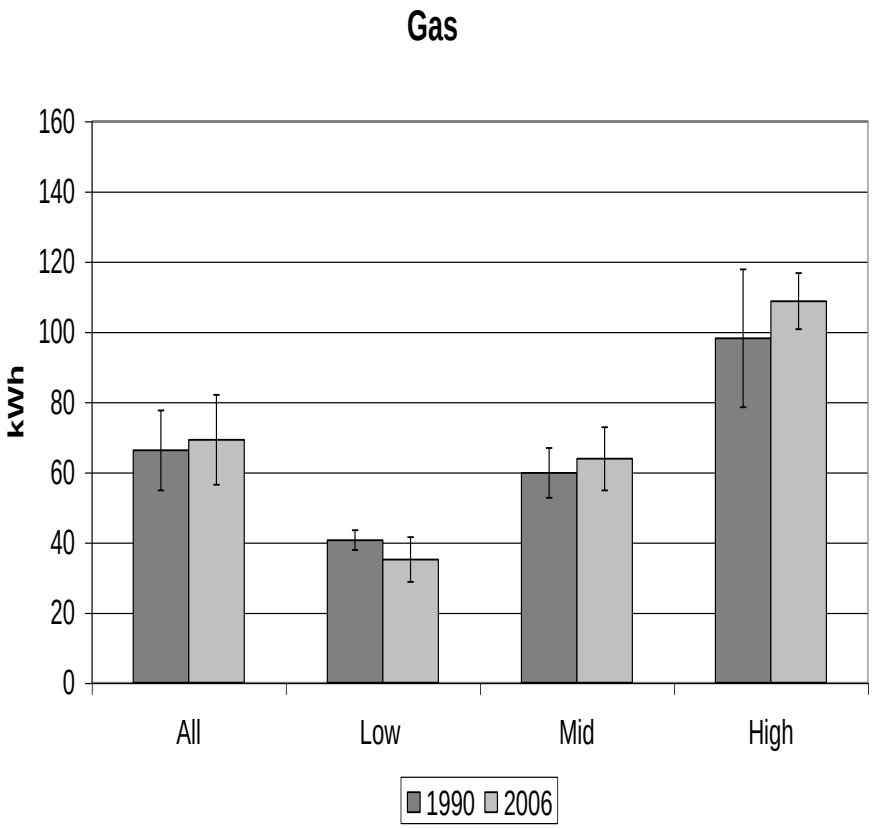
- a population of 30,000 in USA, has managed to cut consumption by 30 per cent in less than a month

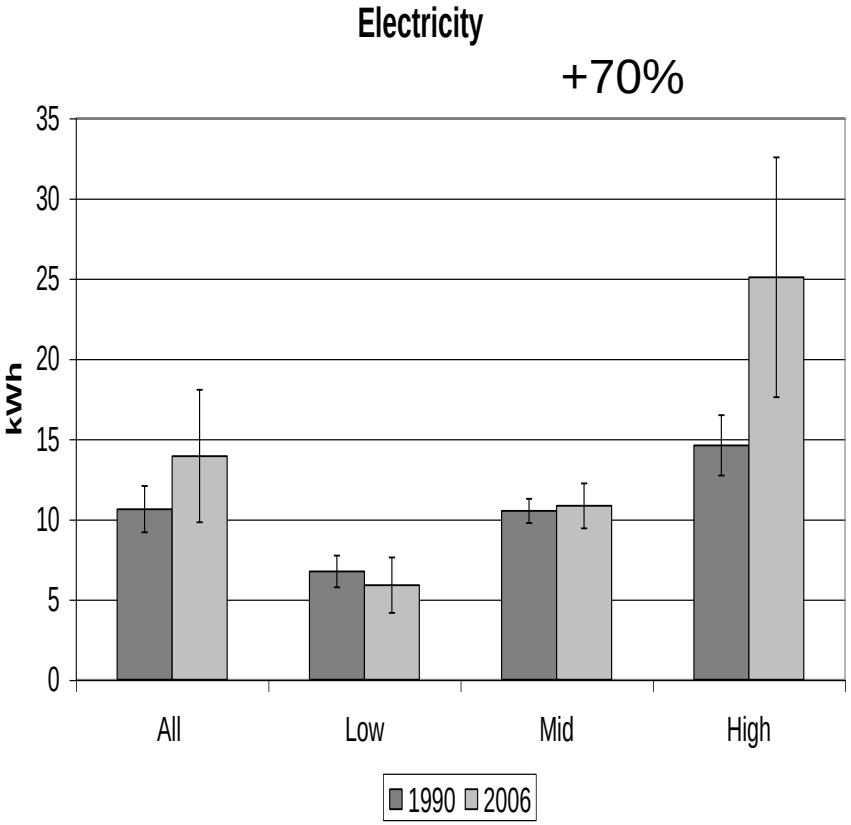
The Independent, 17 May 2008.

- “After 36 years of self-imposed environmental abstinence, Miss Pick, 67, is now being recognised as an eco-heroine with one of the smallest carbon footprints in the country.”
- “She never heats her flat and eats all her food raw”

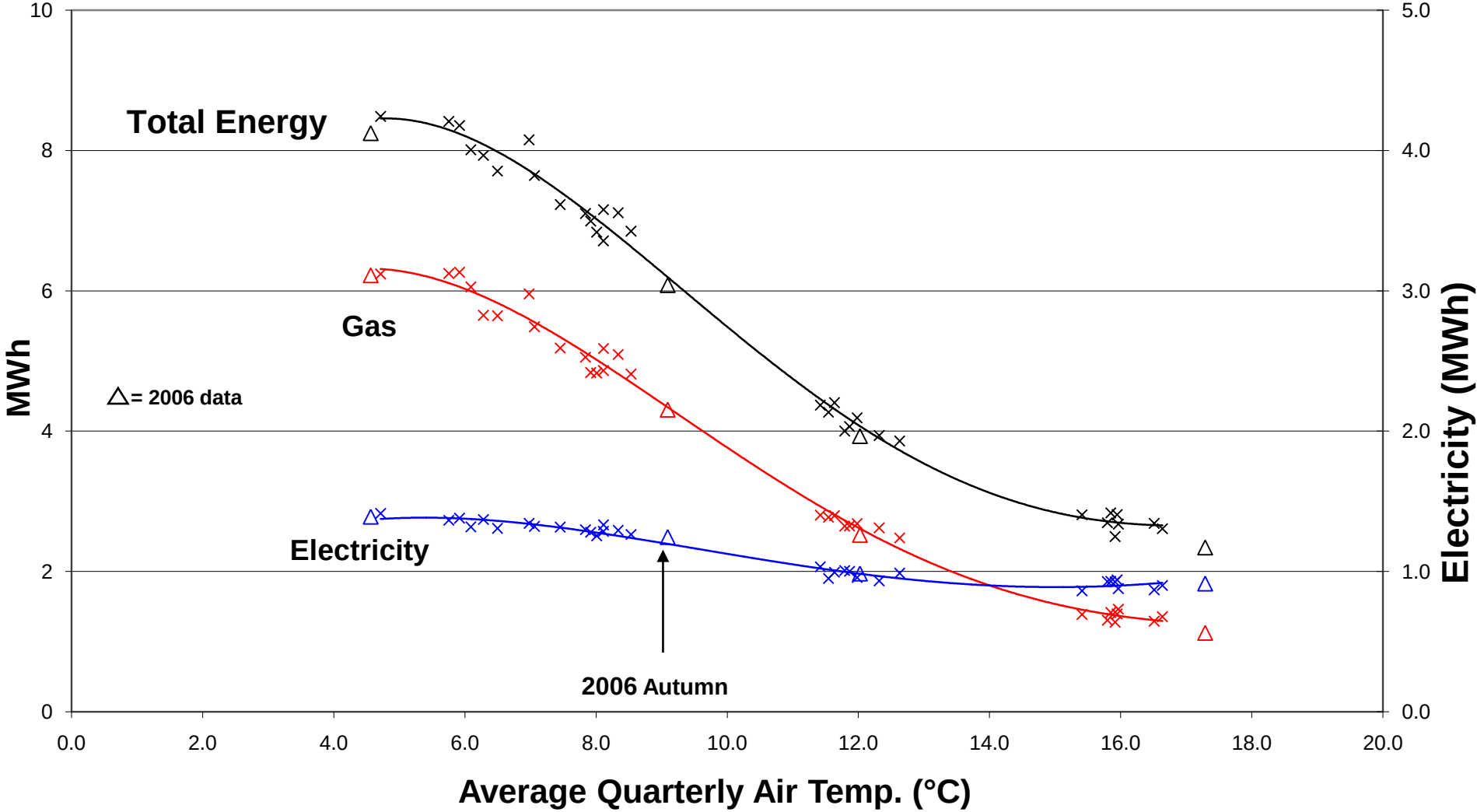
The Times, November 12, 2008

MK 1990 – MK 2006 Energy Usage by Fuel at T_{ext} 5°C



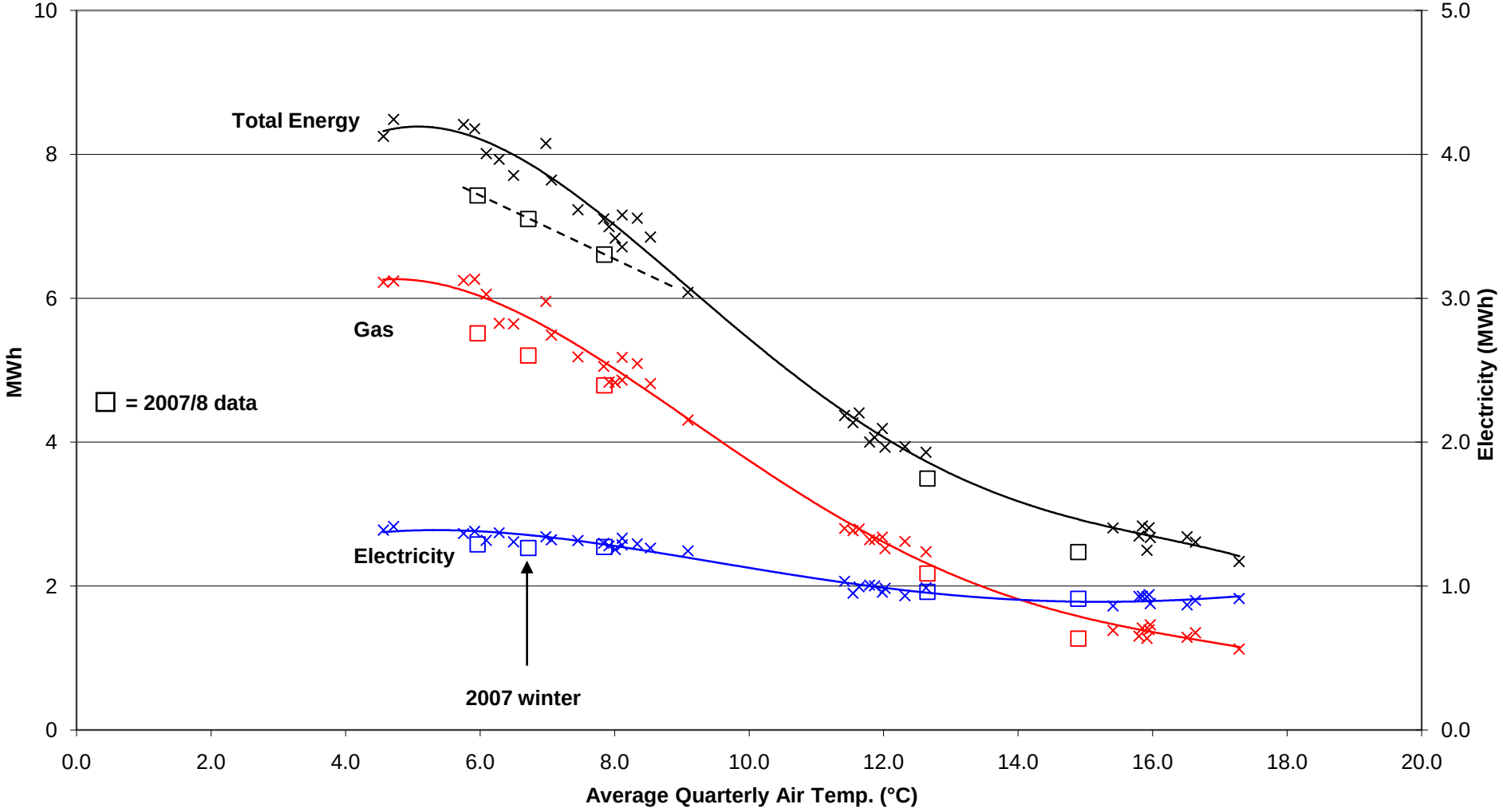


Quarterly Energy Use per Household vs Quarterly Air Temp (1998-2006)



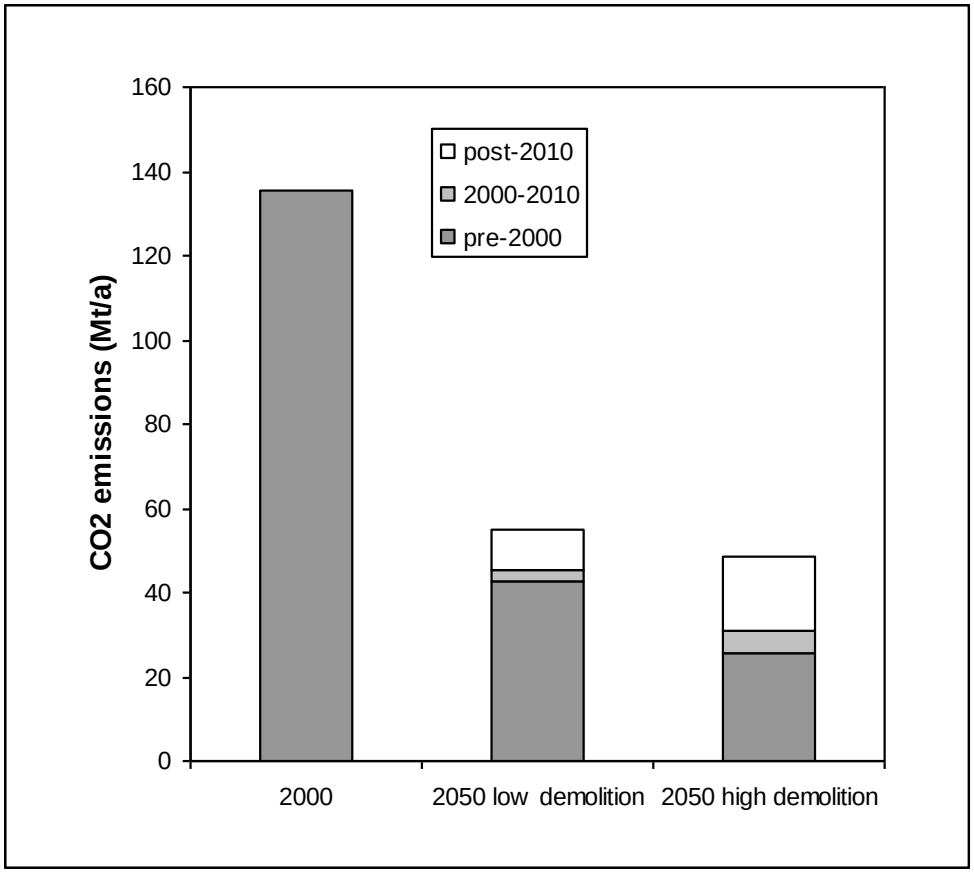
Prepared by Dr Alex Summerfield, UCL

Quarterly Energy Use per Household vs Quarterly Air Temp (1998-2006, 2007-8)



Prepared by Dr Alex Summerfield, UCL

CO_2 emissions…



in 2050:

- electricity 0.2 kg (CO_2)/kWh (= natural gas)
- delivered heat 0.1 kg (CO_2)/kWh
- 40% reduction in delivered energy for heating in pre 2000 dwellings
- electricity use for lights & appliances at 2000 level
- low demolition rate 15,000 per year
- high demolition rate 200,000 per year

Technical options and strategies for Decarbonizing UK housing, Robert Lowe, BRI, 2007

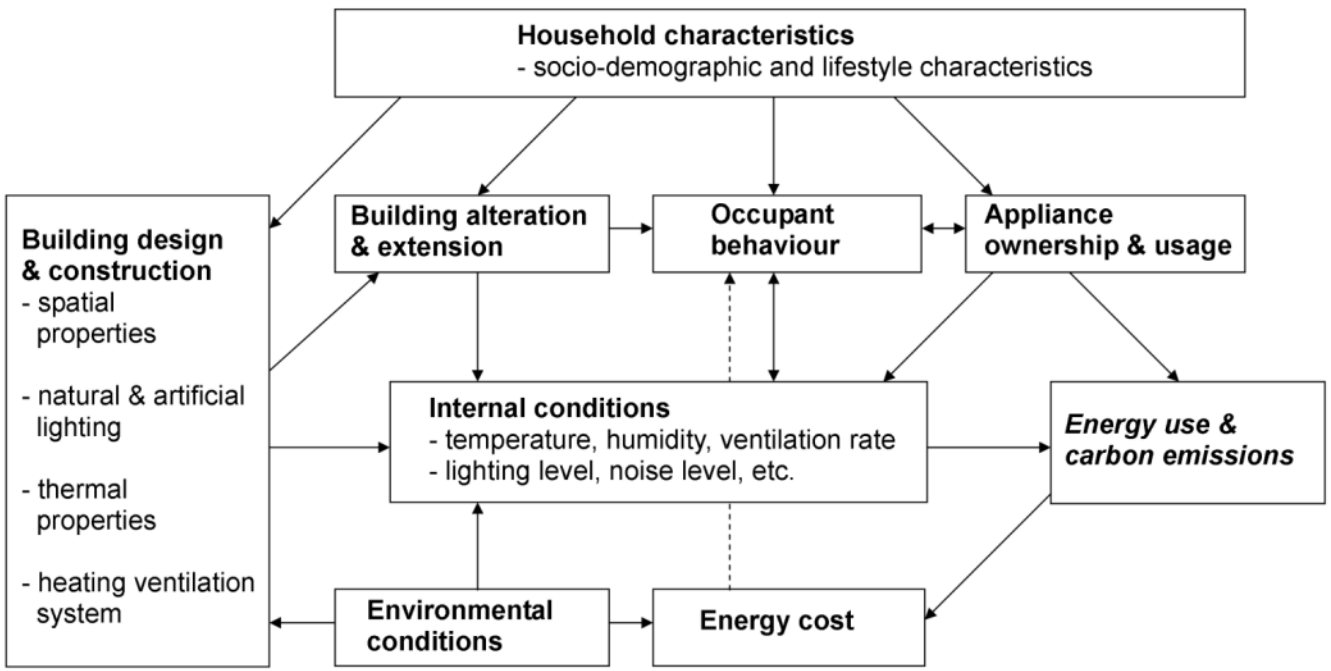
PROBLEM SOLVED ?

Camden Victorian Low Carbon Refurbishment 80% carbon reduction (Code Level 4)

Code Level 6 (Zero Carbon) new house Barrett's Greenhouse

The challenge: How to deploy appropriate technology to 24 million dwellings within a complex socio-economic system to reduce carbon emissions by 60 to 80%

- We have more evidence than we need that technology alone will not deliver
- Technology can play a significant part in the solution or the problem.



A schematic representation of the inter-relationships between occupant behaviour and other factors in influencing energy use in domestic buildings.

Energy usage and occupant behaviour: understanding socio-technical interactions, Summerfield 2008

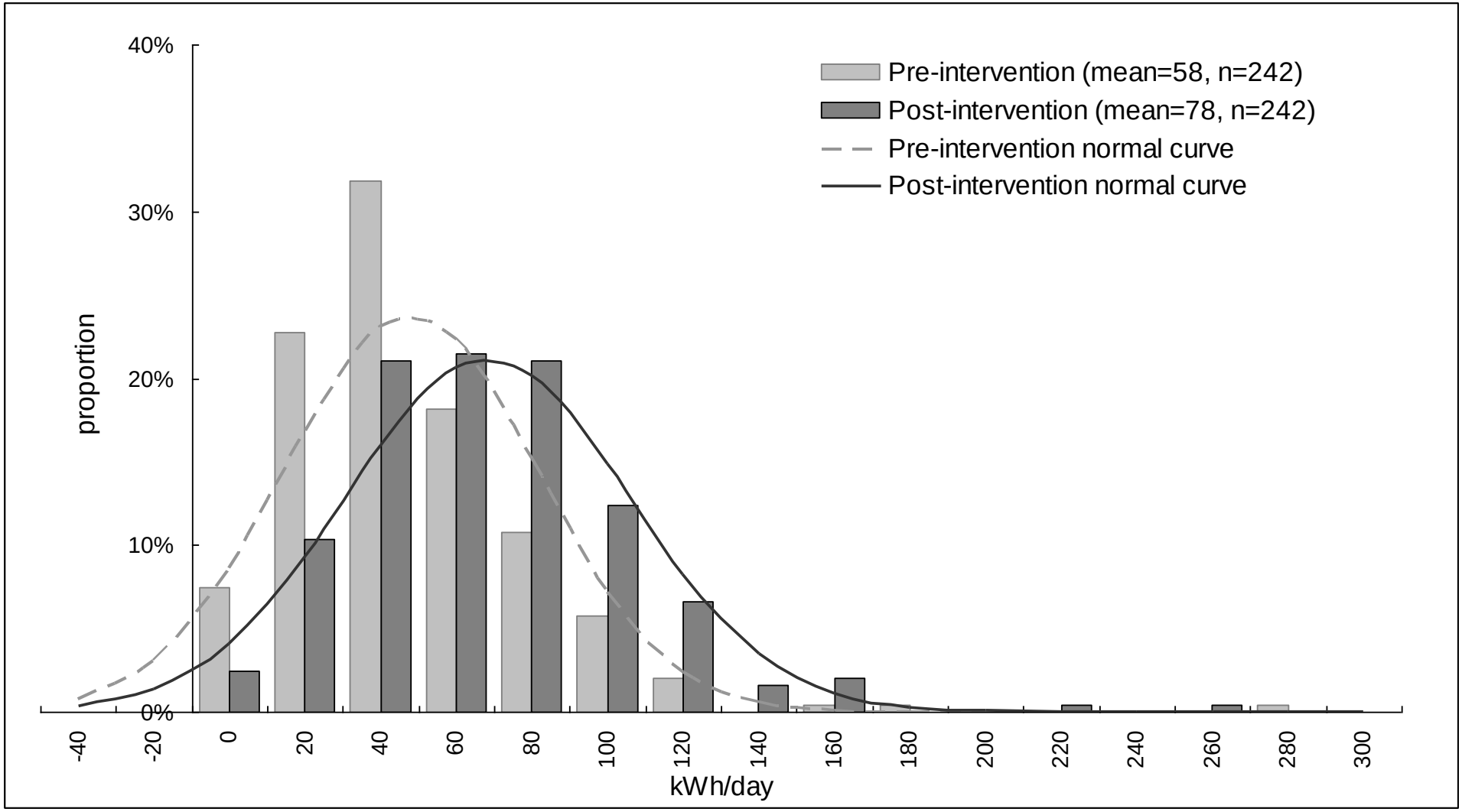
Warm Front Study

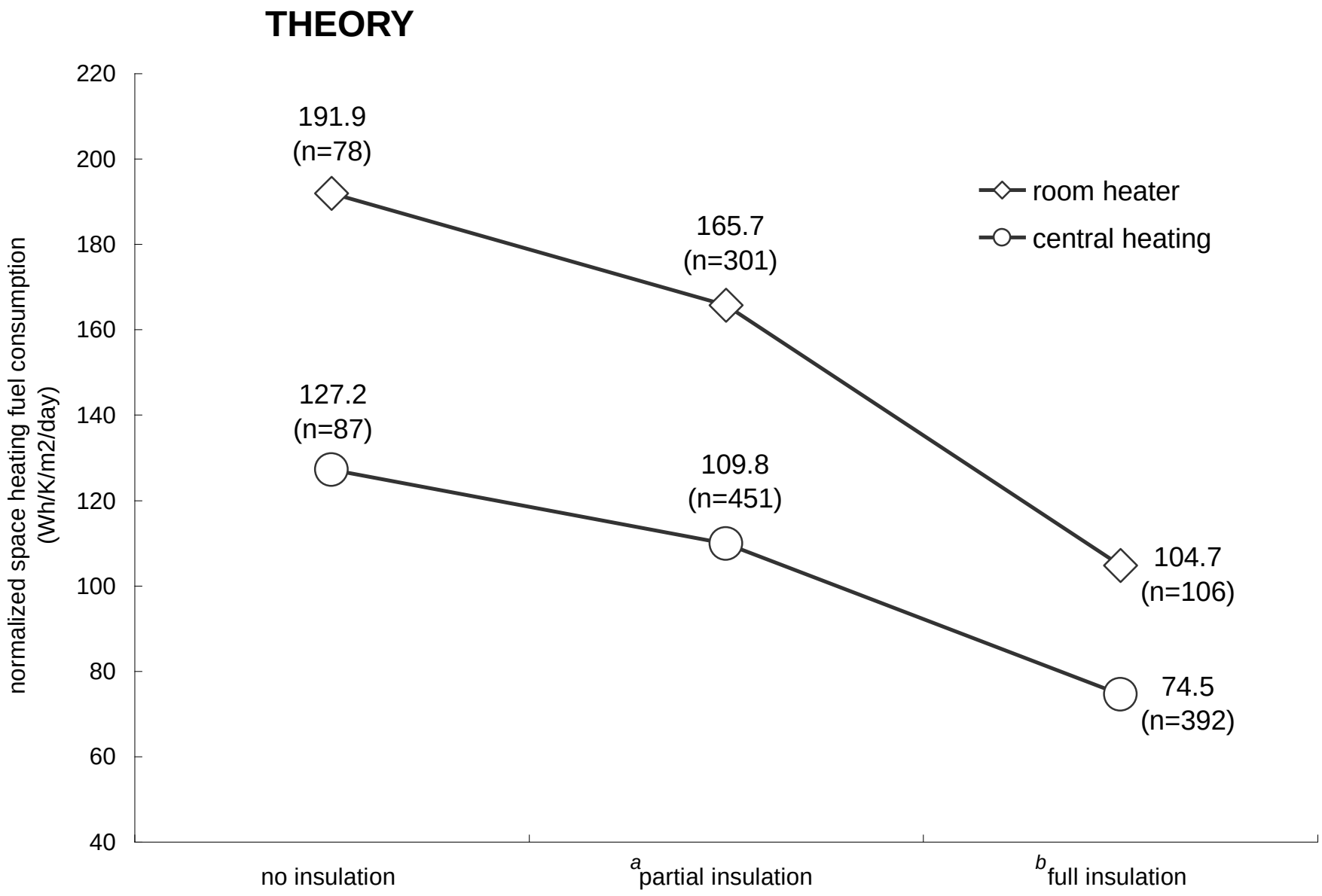
- Insulation
  - Loft
  - Cavity
  - Hot water tank
  - Draught proofing
- Heating
  - Gas or electric room heaters
  - Central heating
  - Timer controls for electric space and water heating
- Other measures
  - Two low energy light bulbs
  - Energy advice
  - Security measures

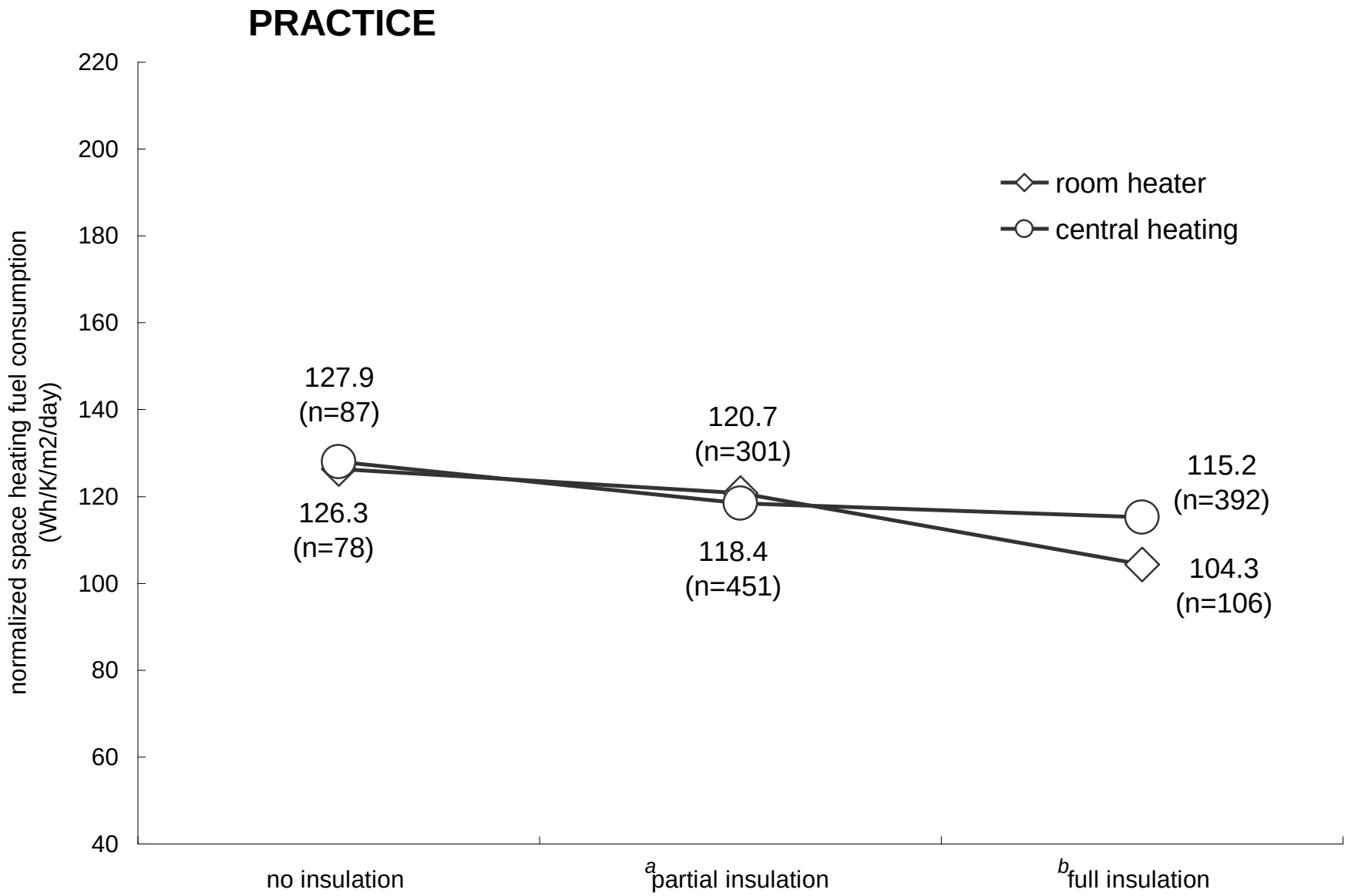
- Up to £2,500 per dwelling

- £350m p.a. programme

(A) Longitudinal total fuel




THEORY
normalized space heating fuel consumption
(Wh/K/m2/day)
220
200
180
160
140
120
100
80
60
40
191.9
(n=78)
165.7
(n=301)
104.7
(n=106)
127.2
(n=87)
109.8
(n=451)
74.5
(n=392)
room heater
central heating
no insulation
a partial insulation
b full insulation


PRACTICE
220
200
180
160
140
120
100
80
60
40
normalized space heating fuel consumption
(Wh/K/m2/day)
room heater
central heating
127.9
(n=87)
126.3
(n=78)
120.7
(n=301)
118.4
(n=451)
115.2
(n=392)
104.3
(n=106)
no insulation
a partial insulation
b full insulation

‘In theory,
theory and practice are the same,
but in practice,
they’re not’

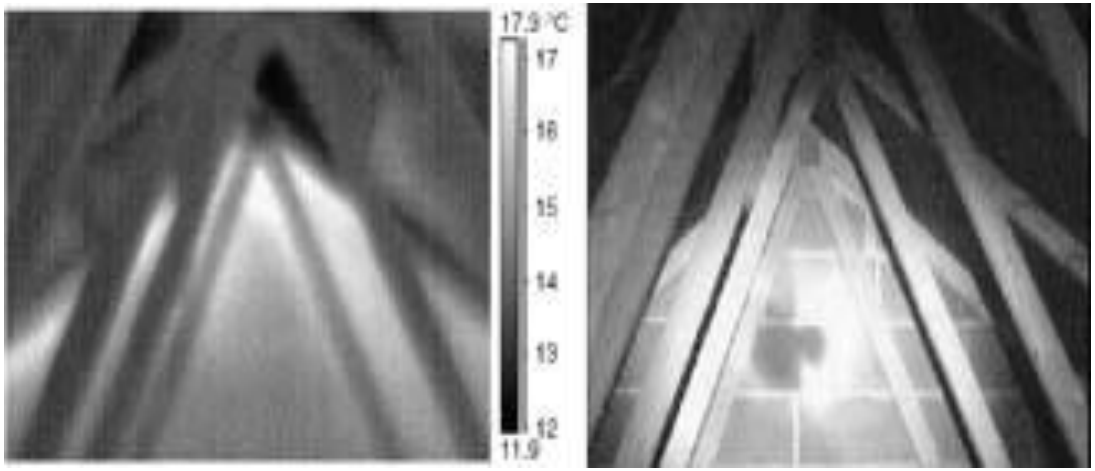
Santa Fe Institute in Factor Four

Why is theory and practice not the same in this case ?

1. Applied physics wrongly
2. Not built/refurbished as modelled
3. Models do not take account of changes in occupant behaviour

PHYSICS APPLIED INCORECTLY: COMPARISON OF AIR INFILTRATION RATE PRE- AND POST-WARM FRONT

	Pre-Warm Front		Post-Warm Front		
WF Scheme	N	Infiltration rate ($m^3/hr/m^2$)	N	Infiltration rate ($m^3/hr/m^2$)	% Change
All properties	78	17.7 (s.d. 7.1)	143	17.0 (s.d. 7.2)	-4%
w/o CH	22	19.1 (s.d. 7.8)	51	16.5 (s.d. 7.3)	-14%
w/ CH	56	17.1 (s.d. 6.8)	92	17.2 (s.d. 7.2)	+1%



Stamford Brook – thermal envelope defects – convective bypasses

(Lowe et al 2007)

Not refurbished as modelled

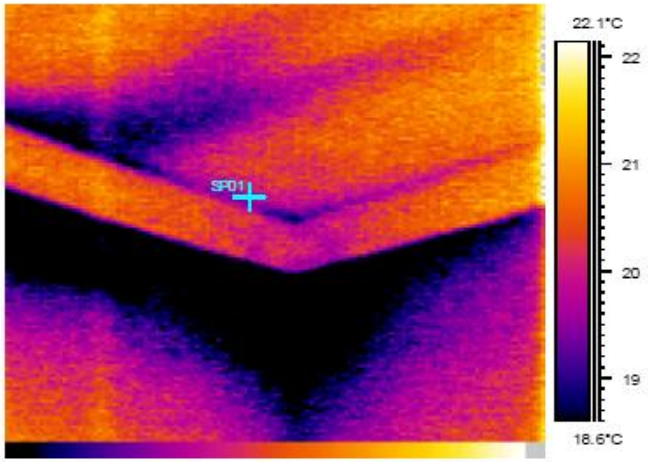
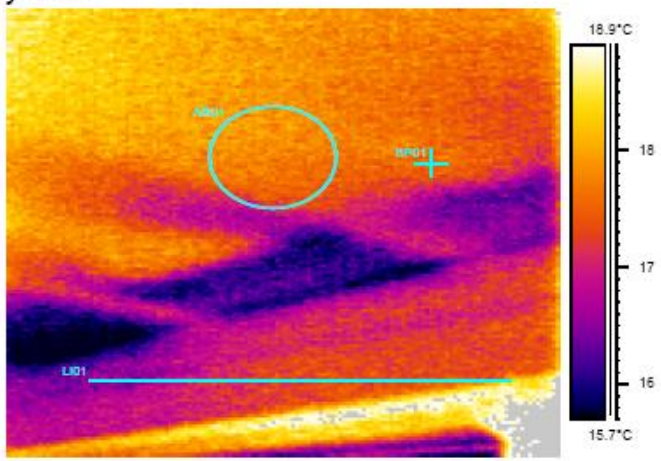


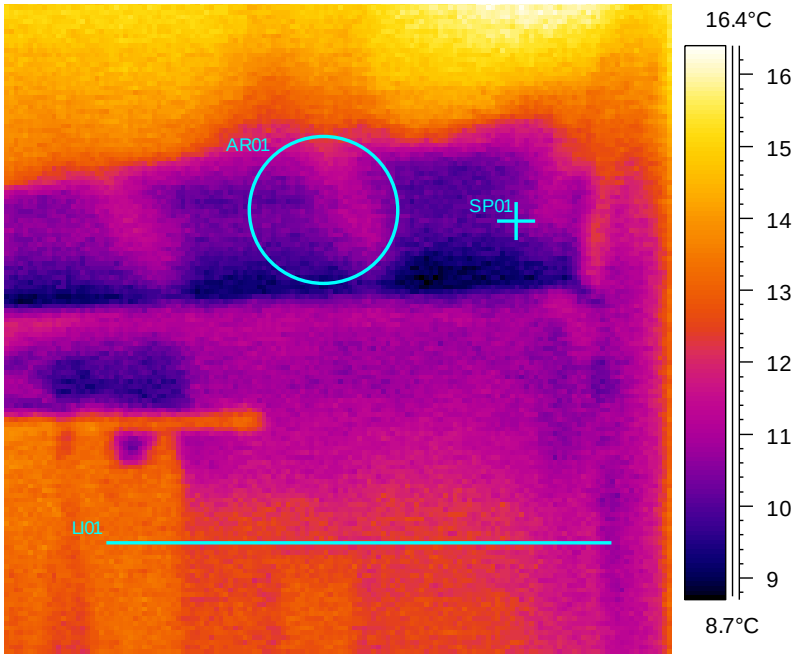
Figure x : Infrared thermography images showing missing cavity wall insulation along the top of the cavity wall



Figures 3: Missing loft insulation along the ceiling edge

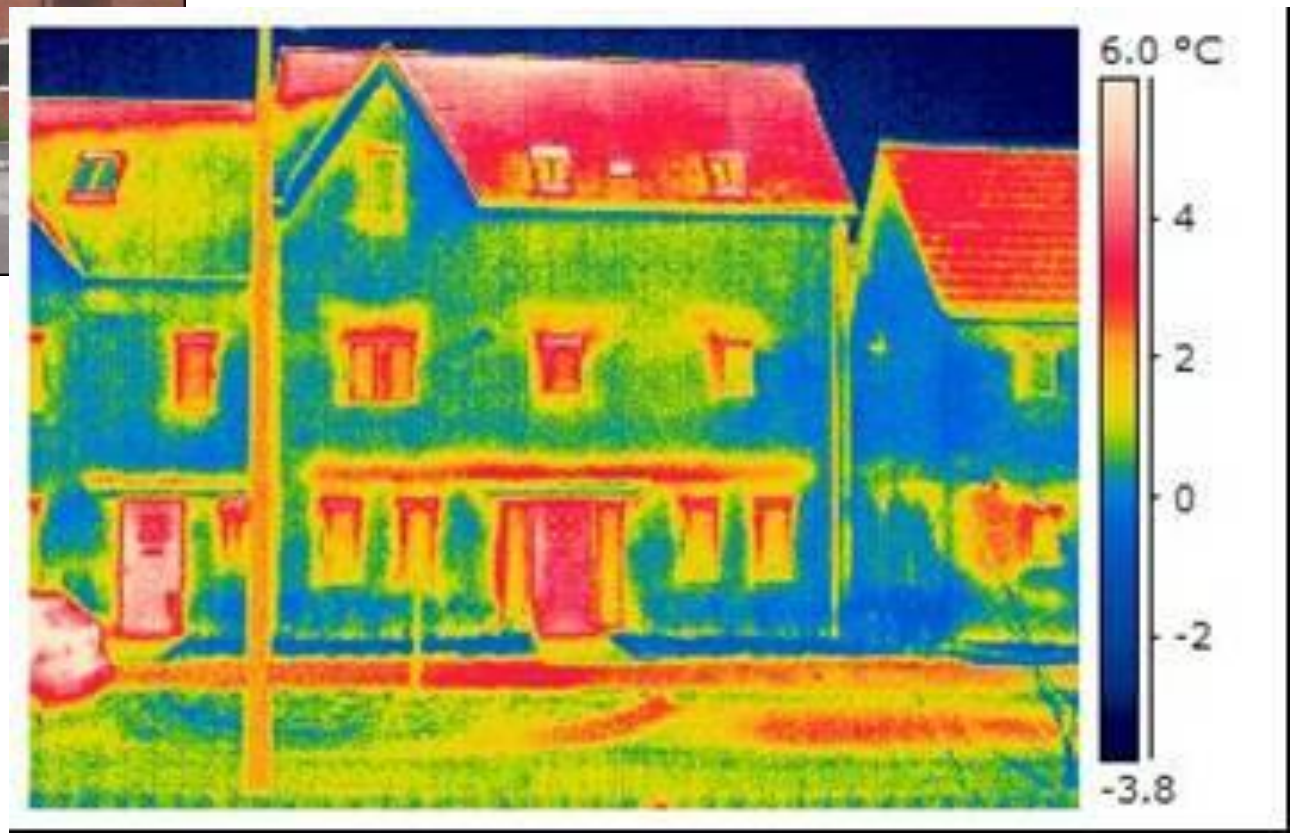
Theoretical U-value is not being achieved

20% cavity wall missing in insulation (n = 85)
13% loft area missing in insulation (n = 85)



Stamford Brook – thermal envelope defects

(www.leedsmet.ac.uk/as/cebe/projects/stamford/summary.htm)



Models do not take account of changes in occupant behaviour

- “Rebound effect”, “Take Back”, “Comfort Factor”, “Take off”
- People interact with complex systems in complex ways
- Note, rebound effect only partly explains the difference between theory and reality and it is not the only change in occupant behaviour that has been incorrectly modelled

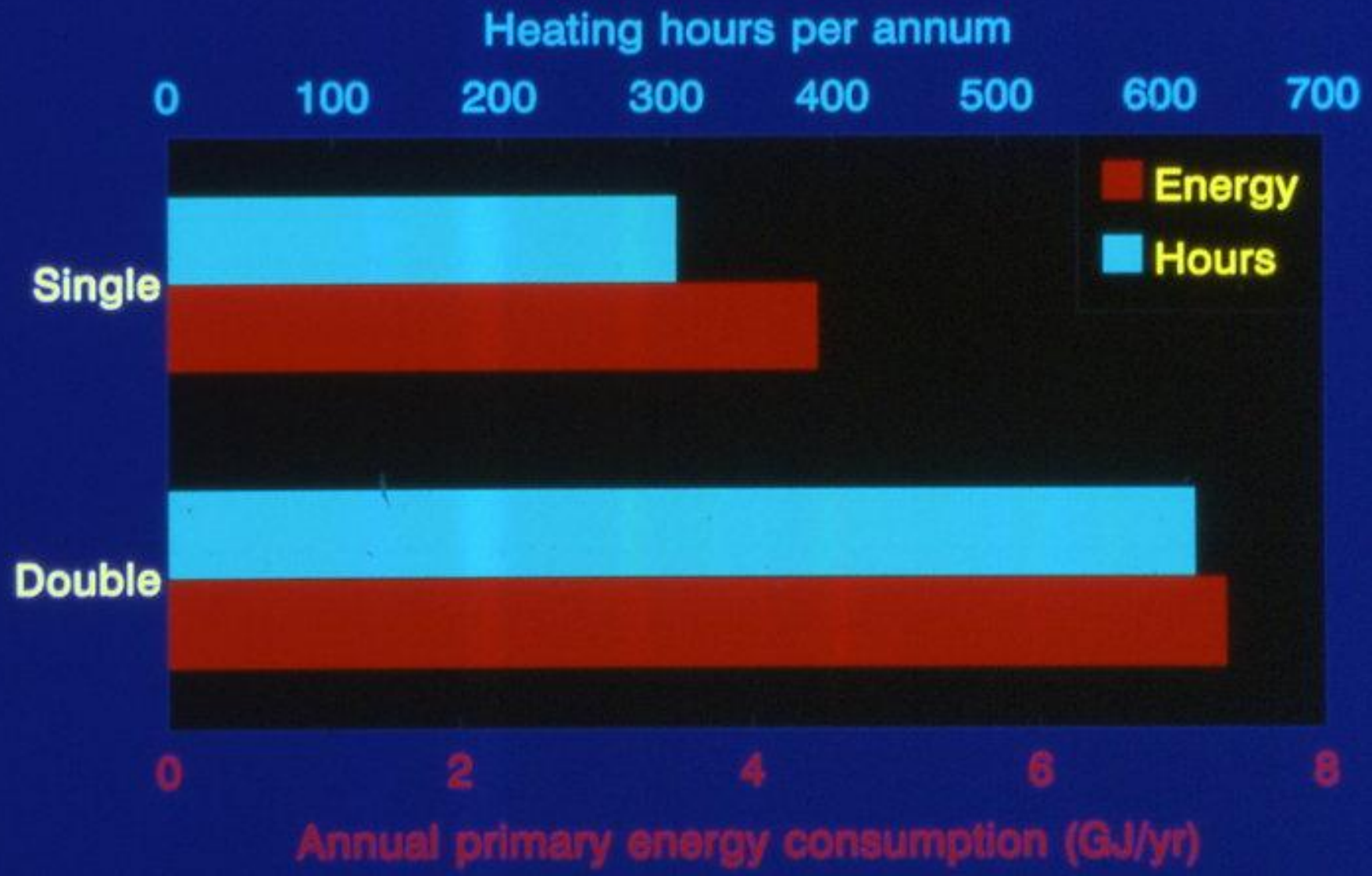
Theoretical boiler efficiency is not being achieved

+

"…*very high proportion of tenants (80%) used some combination of gas fire and central heating.*"

(Energy efficient modernisation of housing: a UK case study, Bell, Lowe, 2000)

Predicted average annual primary energy and hours of heating



AIR CONDITIONING UNIT

342 (h) x 520 (w) x 560mm (d)

710-257

Ideal for a cooler and more comfortable environment in hot weather

Also includes a heat pump for all year round use

Can be installed in offices, houses and conservatories

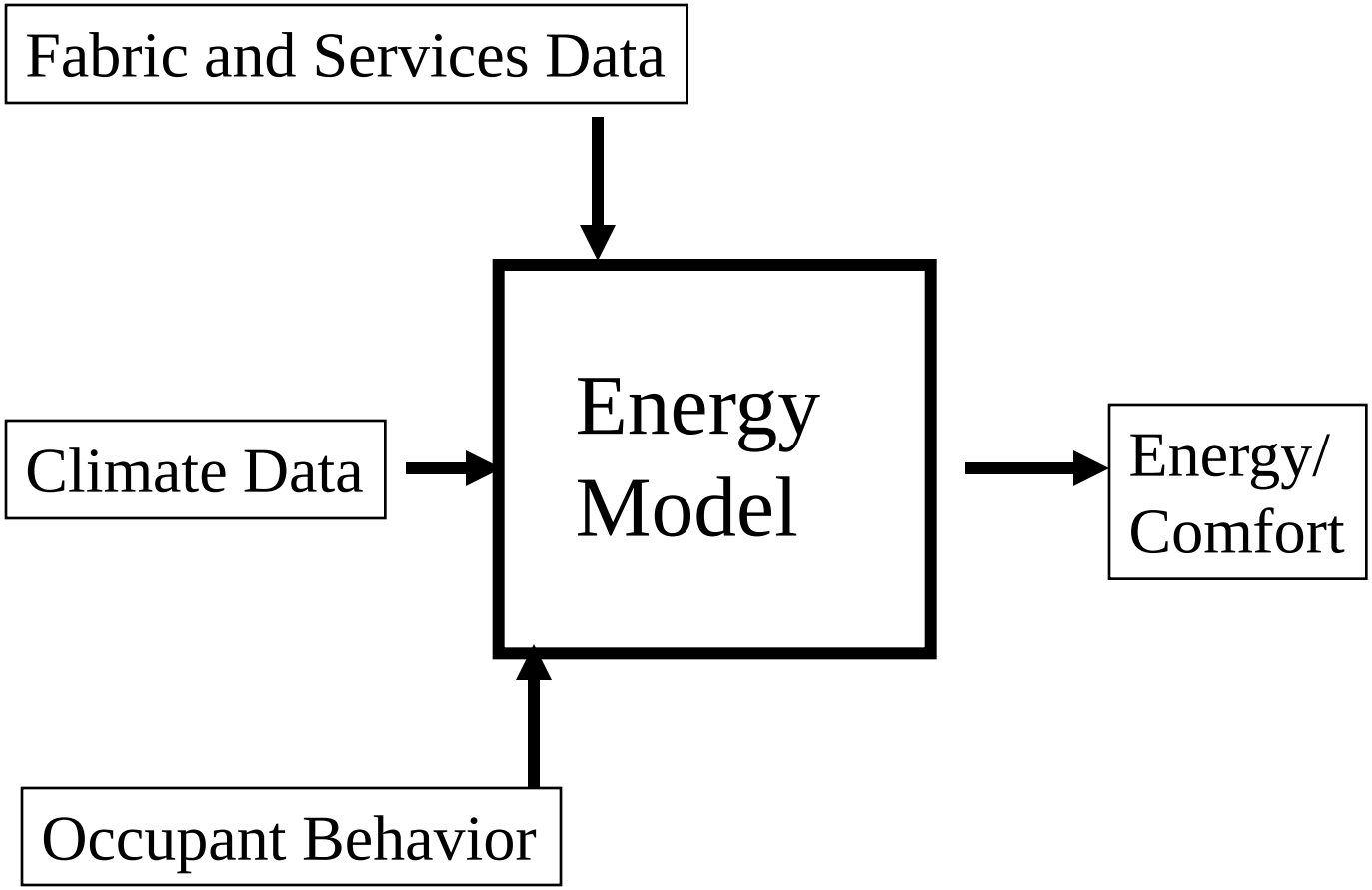
Features include:

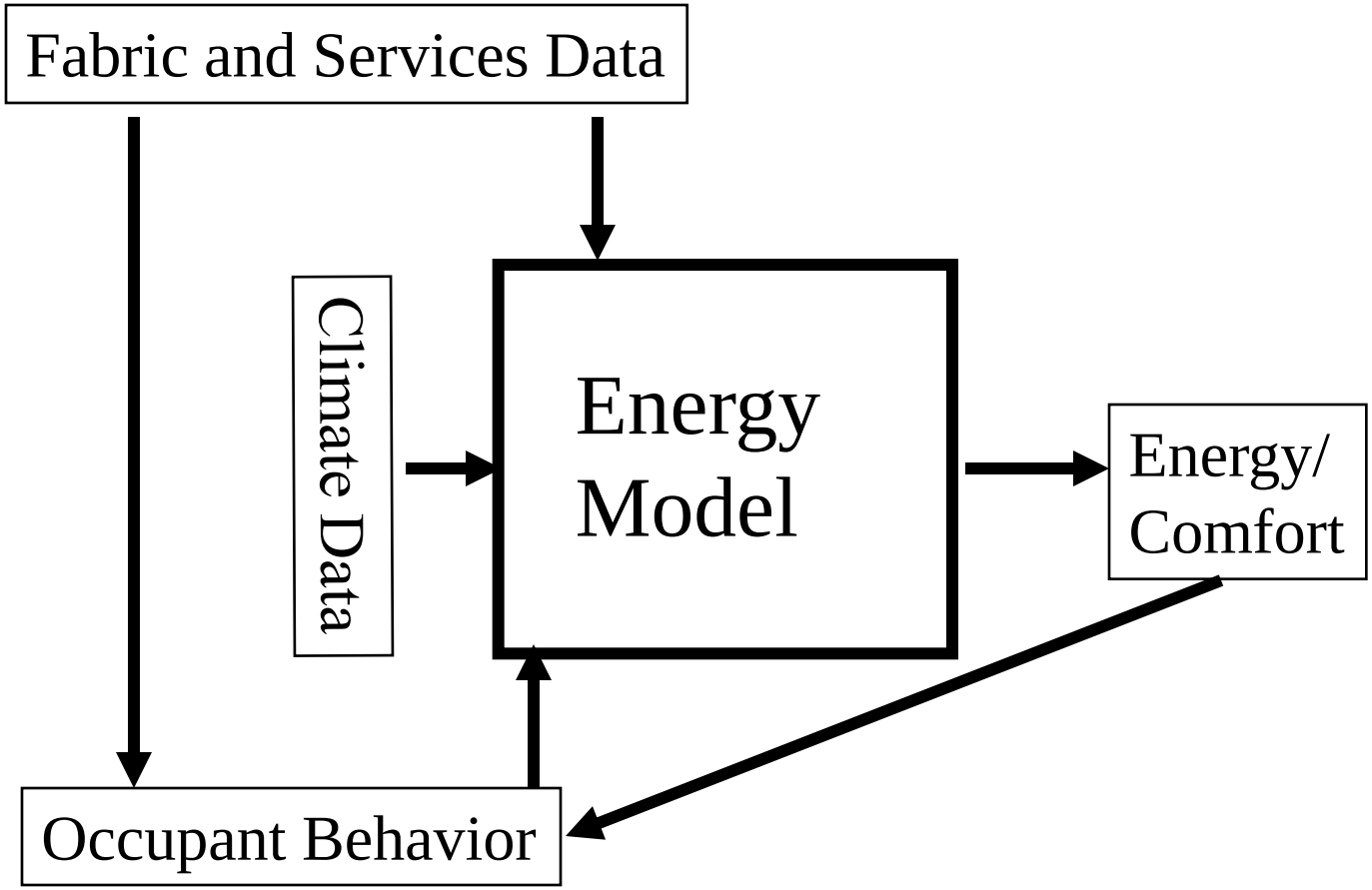
- Cooling capacity – 8500Btu/hr
- Heating capacity – 8500Btu/hr
- Automatic Thermostat
- Quiet operation
- 3 Year Warranty

Fixing kits available, sold separately, see in store for details. (Not included in price)

ONLY £349.99

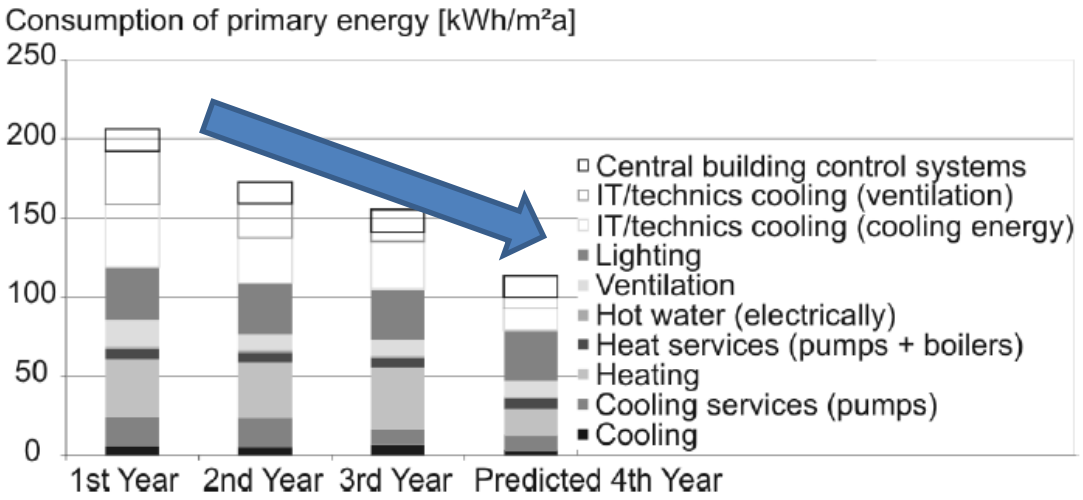
ALL PRICES INCLUDE VAT


Fabric and Services Data
Climate Data
Energy Model
Energy/ Comfort
Occupant Behavior


Fabric and Services Data
Climate Data
Energy Model
Energy/ Comfort
Occupant Behavior

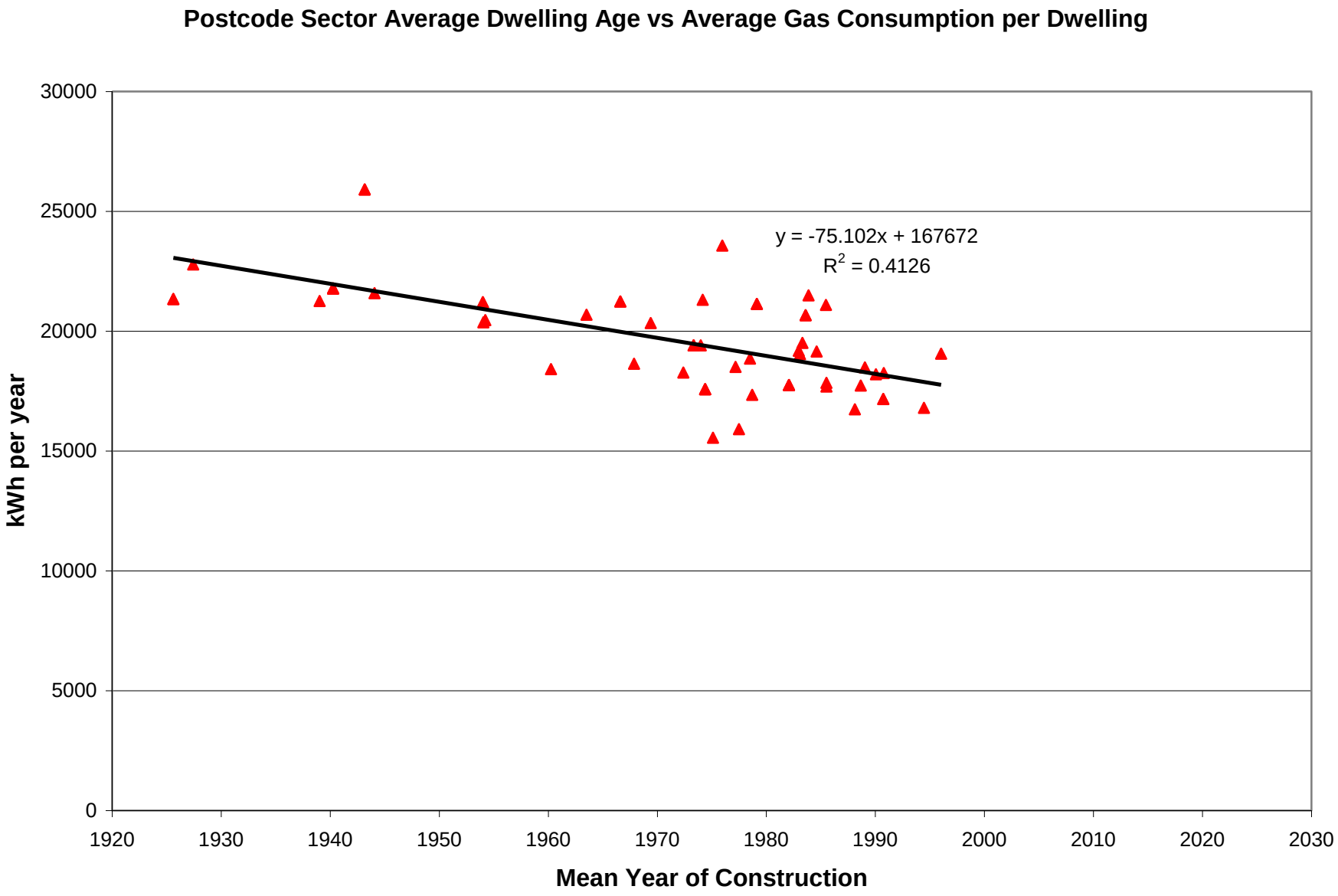
The UK is not alone: Factor 2

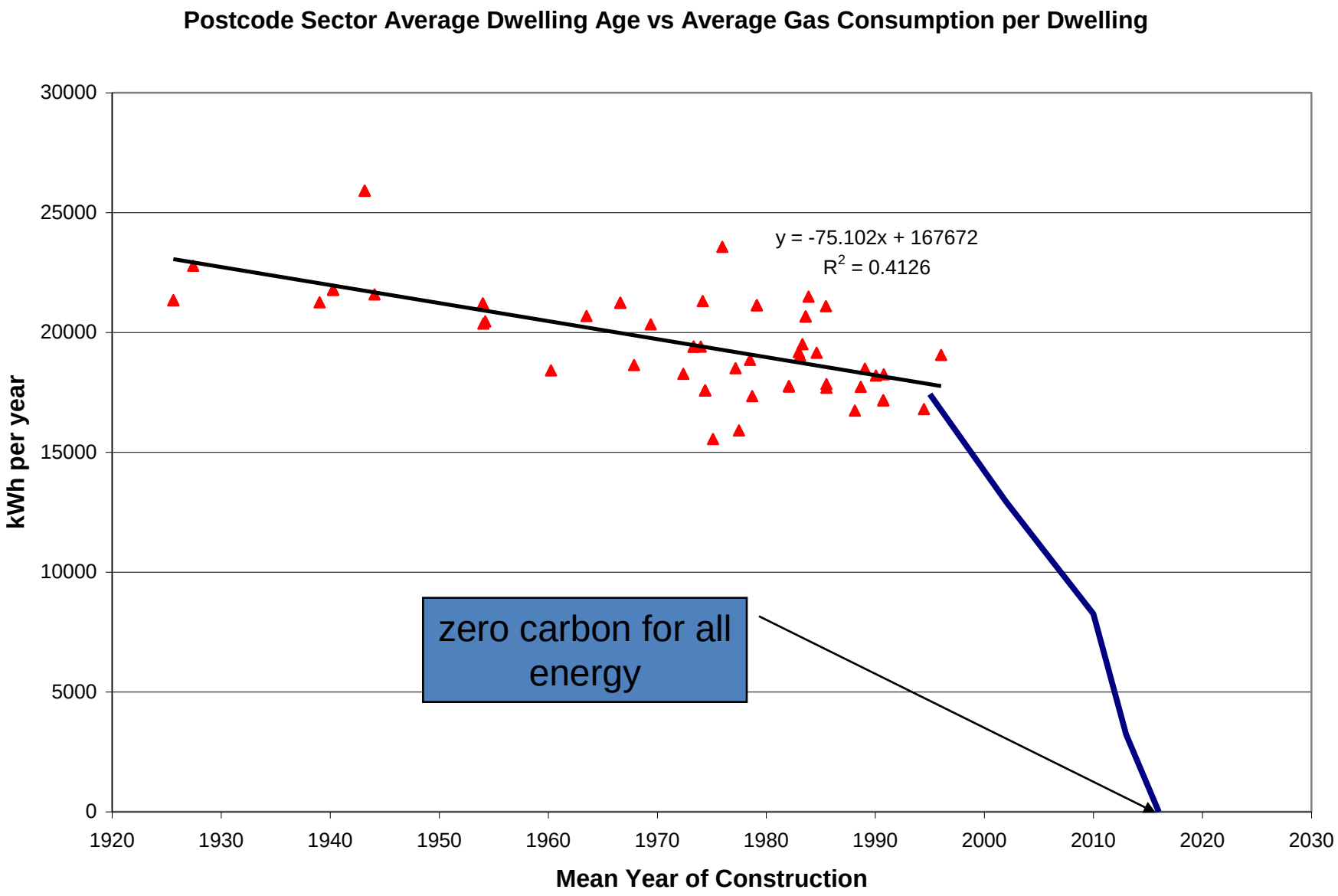
Non-domestic whole building



- The “East Arcade”, a new extension building of the KfW bank group, is situated in the middle of Frankfurt, Germany.
- Naturally ventilated and passively cooled
- UCL KTP (issue of concern for building designers in UK)

International Journal of Ventilation ISSN 1473-3315 Volume 6 No 1
Monitoring Results of a Naturally Ventilated and Passively Cooled Office Building in Frankfurt, Germany
Andreas Wagner, Michael Klebe and Christopher Parker


Postcode Sector Average Dwelling Age vs Average Gas Consumption per Dwelling
y = -75.102x + 167672
R2 = 0.4126
kWh per year
30000
25000
20000
15000
10000
5000
0
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030
Mean Year of Construction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30000
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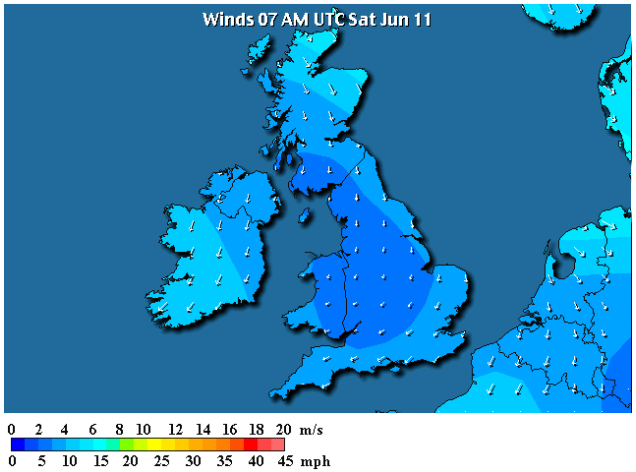
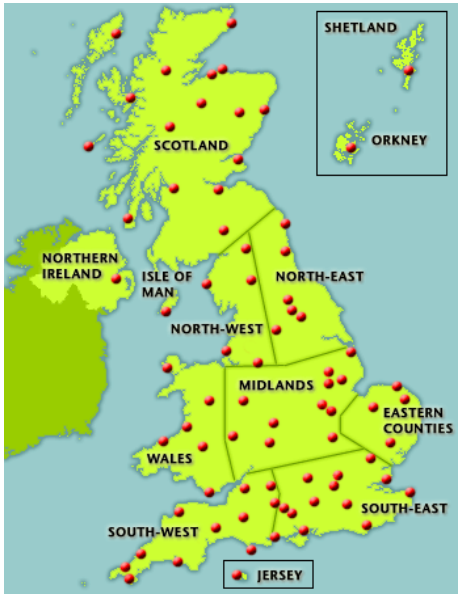
1950
1960
1970
1980
1990
2000
2010
2020
2030
Mean Year of Construction
y = -75.102x + 167672
R2 = 0.4126
zero carbon for all energy

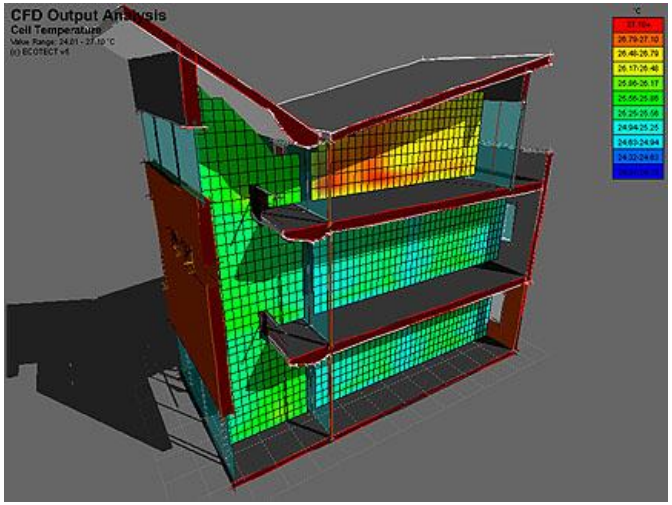
So what do we need to do to get better agreement between theory and reality?

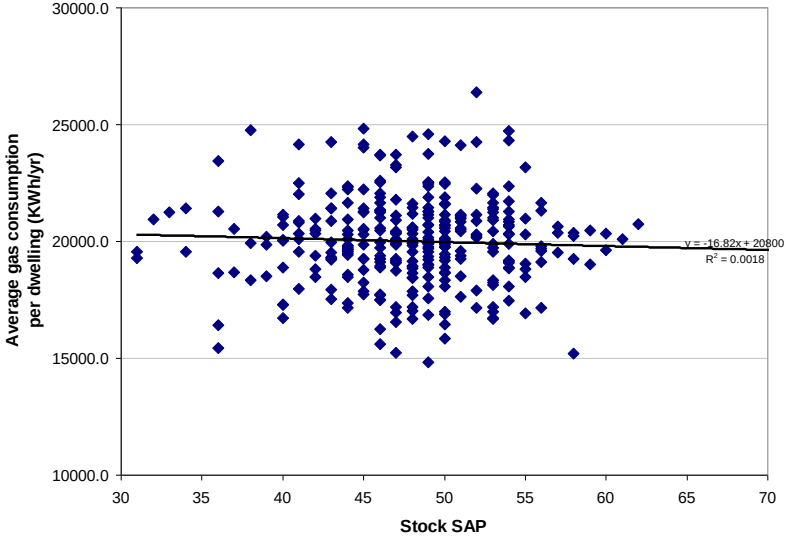
- Work with industry to improve better site practices, supply chains etc. Action research with rapid monitoring and feedback.
- Socio-technical models with feedback that can answer what impact will fuel price rise have on “Take back”.
- Access better data to ground models

Models require relevant data









Superinsulated Houses (1985)

http://www.thimkagain.co.uk/mk/past-projects.htm

Code Level 6 (2008)

http://www.bsjonline.co.uk/Journals/Builder_Group/Building_Services_Journal/July_2007/attachments/Diagram.pdf

23 years

What are the research and other needs to make them happen?

- A radical change in the way that research is funded and co-ordinated in this sector.
- A major study of energy use and overheating in (5,000) buildings.
- National Energy and Buildings Data centre bringing together energy , building, occupancy data
- Development of a second generation UK demand-supply, socio-technical stock model
- Technology development program
- Existing stock heat loss reduction programme (50, 500, 5k, 50k, 500k)
- 10% of all new buildings monitored via smart meters
- Distributed storage research program
- Strong leadership and long term planning including a clear indication of the future pricing of energy, energy sources and decarbonisation of supply plus policy direction regarding regulation etc.

Where should we be in 2020? - Transition

- All new homes should be being built to Passive house standards (Code 4)
- Existing cavities, lofts etc all filled.
- Several large district heating systems installed and the start of a national heat supply system,
- All homes have smart meters
- Real fuel prices increases by 4% p.a. (? 5x by 2050) causing changes in behavior.
- The introduction of an annual energy MOT for buildings.
- The development of a energy refurbishment industry 0.5M per annum (£5 to 10 billion per annum)
- Initial research program completed including development of new materials and deployment strategy validated.

Where should we be in 2050? – Low Carbon economy

- Building heat loss reduced to 50% via a multi-billion pound program of street by street insulation.
- Average house has water saving features and solar water heaters.
- Heating moved from gas based to waste heat, biomass, solar or electric heat pump (ground or air) from low carbon sources with electricity down to 0.2 kg (CO_2)/kWh.
- Fuel prices risen by a factor of 5.
- Utilities paying for local storage within buildings.
- Novel insulating technologies in wide spread use.
- Space standards reduced to both reduce domestic energy consumption and to enable people to live close to their place of work.
- Energy is predominately costed on peak power rather than total energy used.
- Smart metering not only controls all appliance but also self reports and/or self corrects faulty equipment or excessive heat loss.
- All electrical equipment requiring physical presence of an occupant to enable it to use more than 0.1 W of energy. Average appliance electric consumption reduced by 80%

60% fridge (measured, 2008), 80% by 2050 assuming factor 2 decarbonisation of grid

Where should we be in 2100 ?

Where will WE be in 2100 ?

Fig.1 Experimental set-up for solar cremation in Baroda, India, with two axis tracking of the sun.

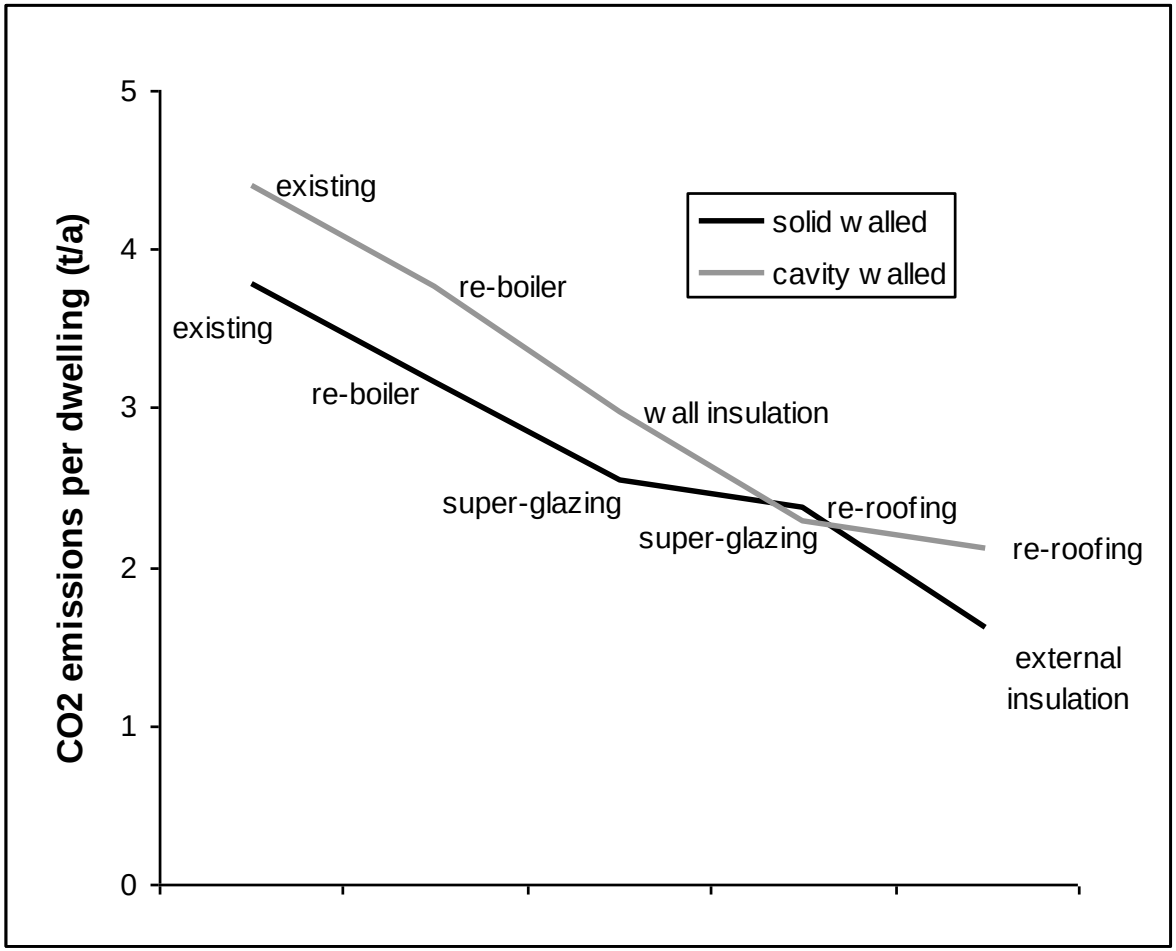
www.solare-bruecke.org

- We hope this will take the form of a one paragraph summary of each of the presentations over the two days focussing on key facts and figures. In order to give the document some consistency of style we would propose writing the summary based on your presentation. In order to facilitate this we would be very grateful if you could provide us with details of your presentation as early as possible.

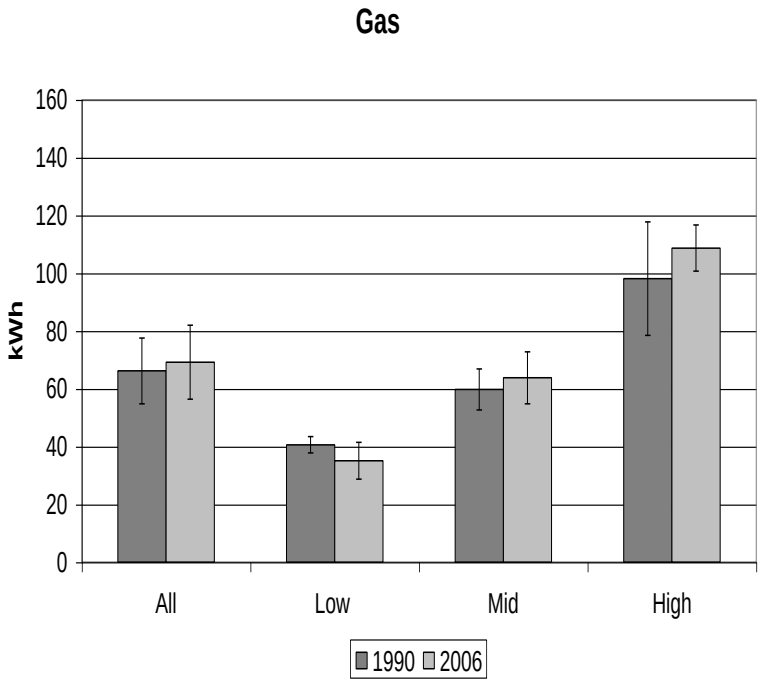
UK domestic envelope statistics:

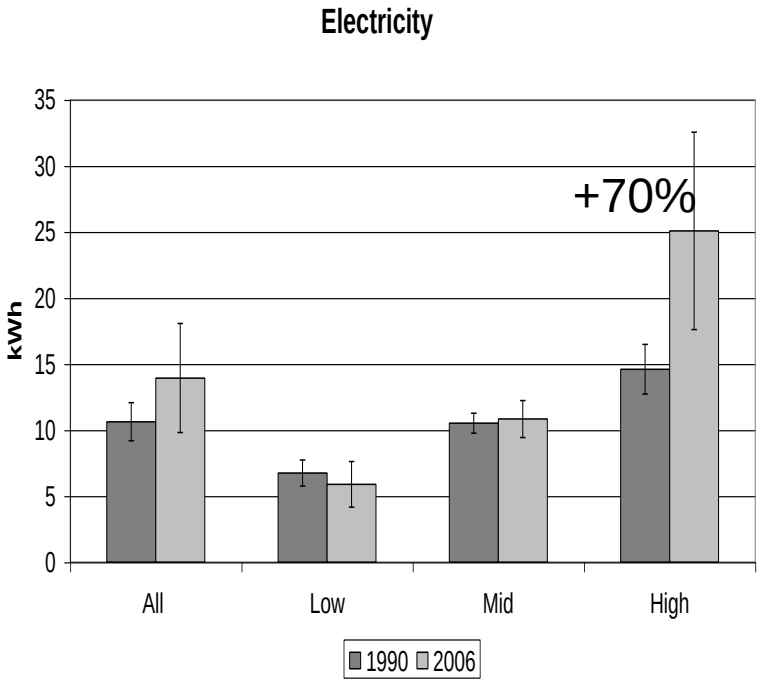
	2008	2050
total envelope area km^2	4400	6500 ?
total volume of insulation km^3	0.4	1.3 ?
total heat loss GW/K	6	4.5 ?
peak heat demand GW	250	100-200 ?

options for improving existing dwellings



MK0 - MK2 Energy Usage by Fuel at T_{ext} 5°C





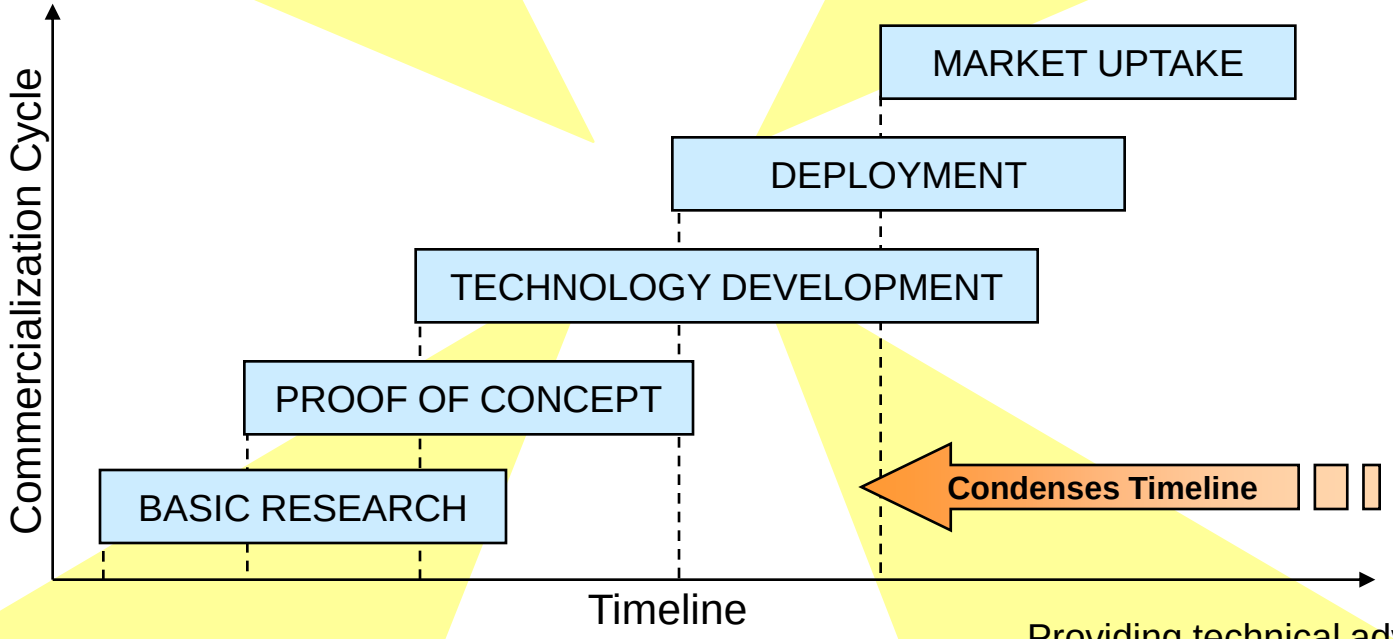
Accelerating Commercialization

S&T

Researching and developing new innovations in building energy technology, programs and processes

Tech Transfer

Knowledge and tools to enhance industry training and to develop Canadian capacity



Involved from initial concept to market uptake

Product Development

Providing technical advice, standards, guidelines and program specifications

Program Support

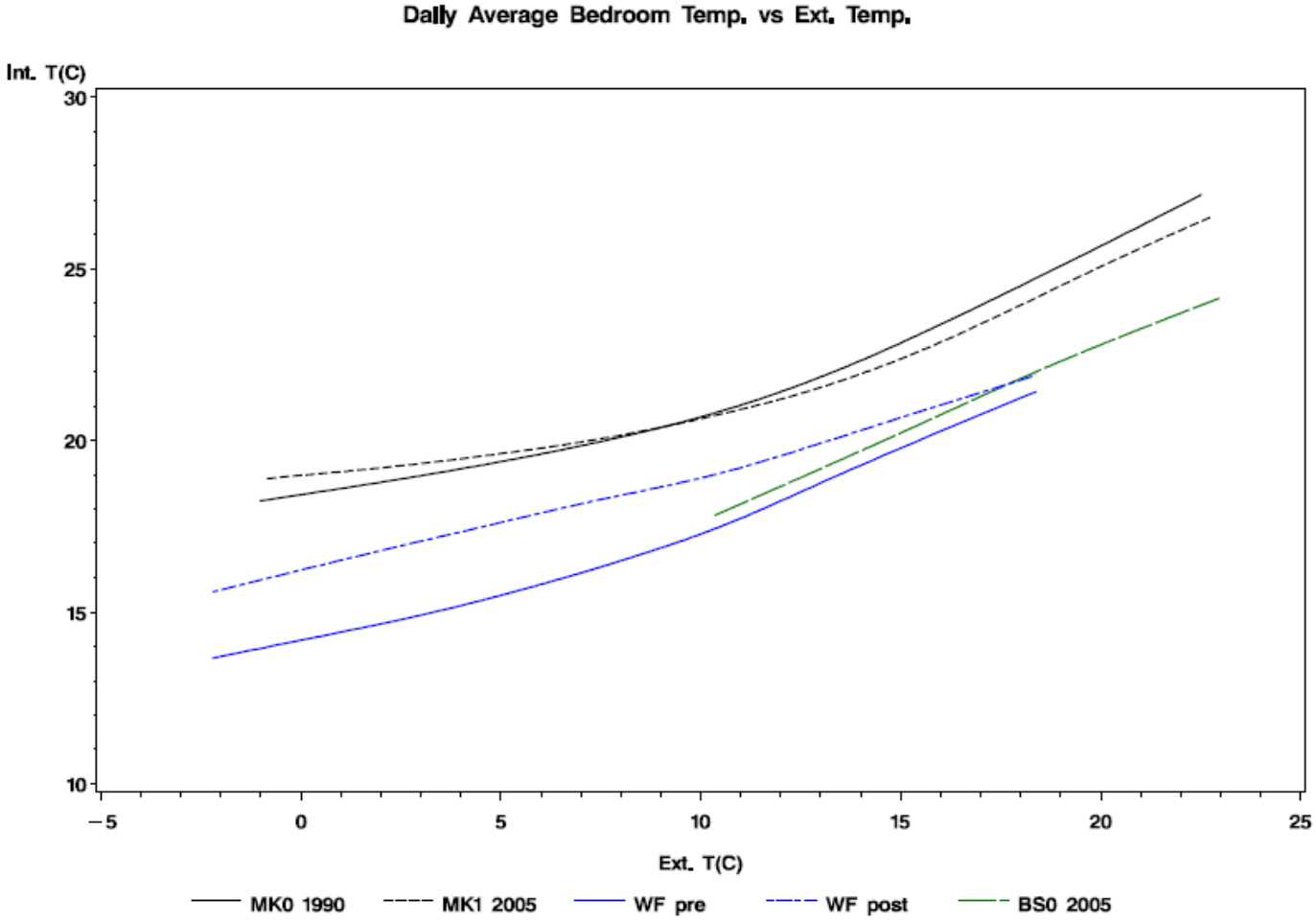
Milton Keynes Energy Park

Typical Phase 1
SAP approx 75

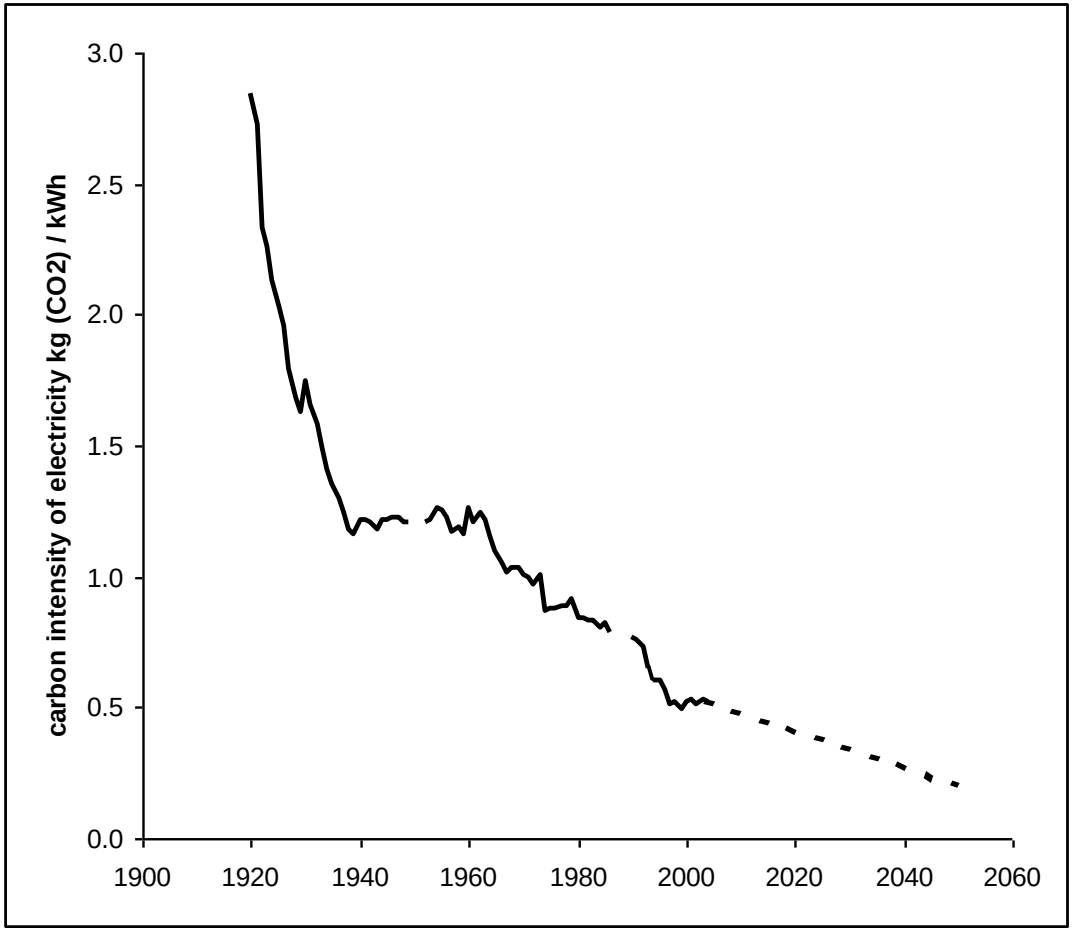
Typical Phase 2
SAP approx 90

- Built 16 years ago and intensely monitored
- 28% reduction in fuel consumption compared to the then housing stock
- Gas consumption 41% lower than the National housing stock

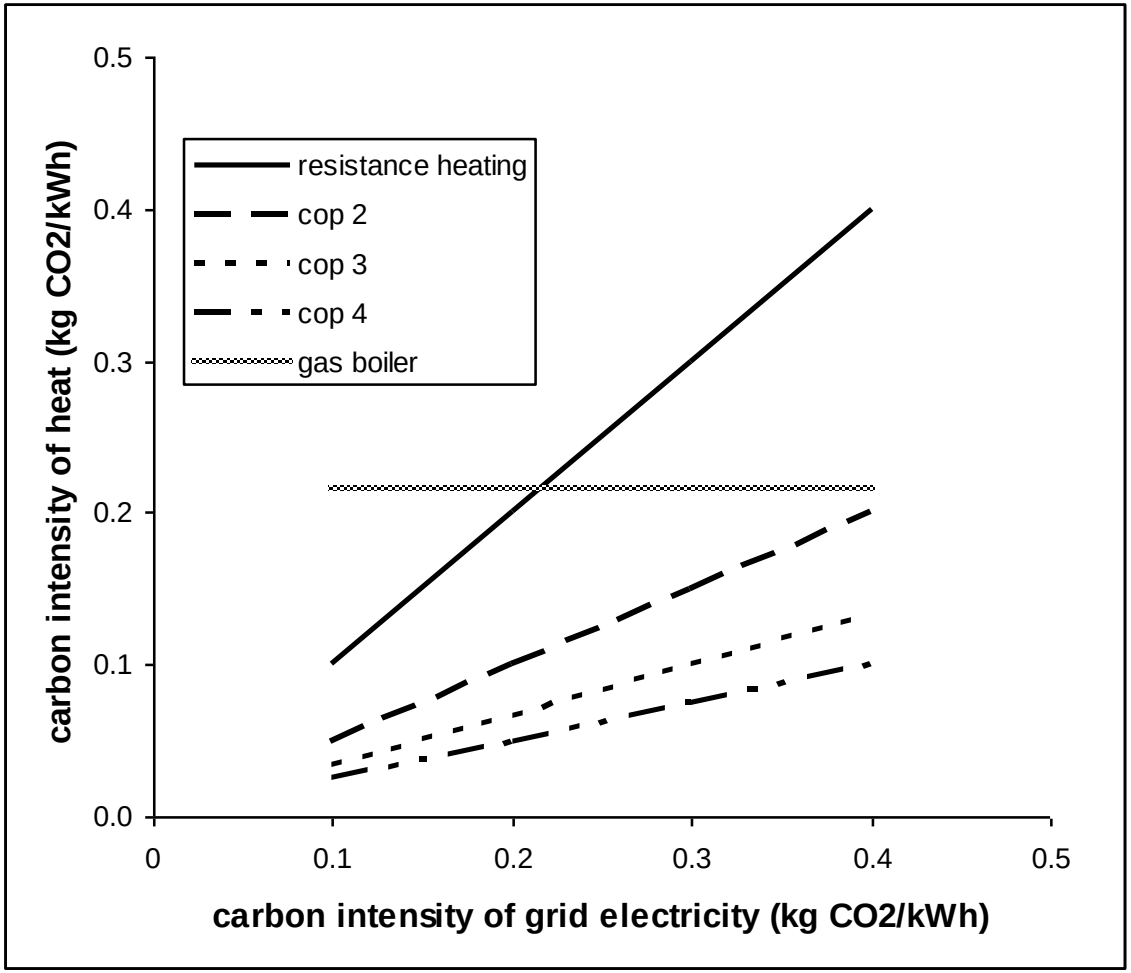
Average bedroom temperatures in various studies



decarbonising the electricity supply system



decarbonising heat supply…

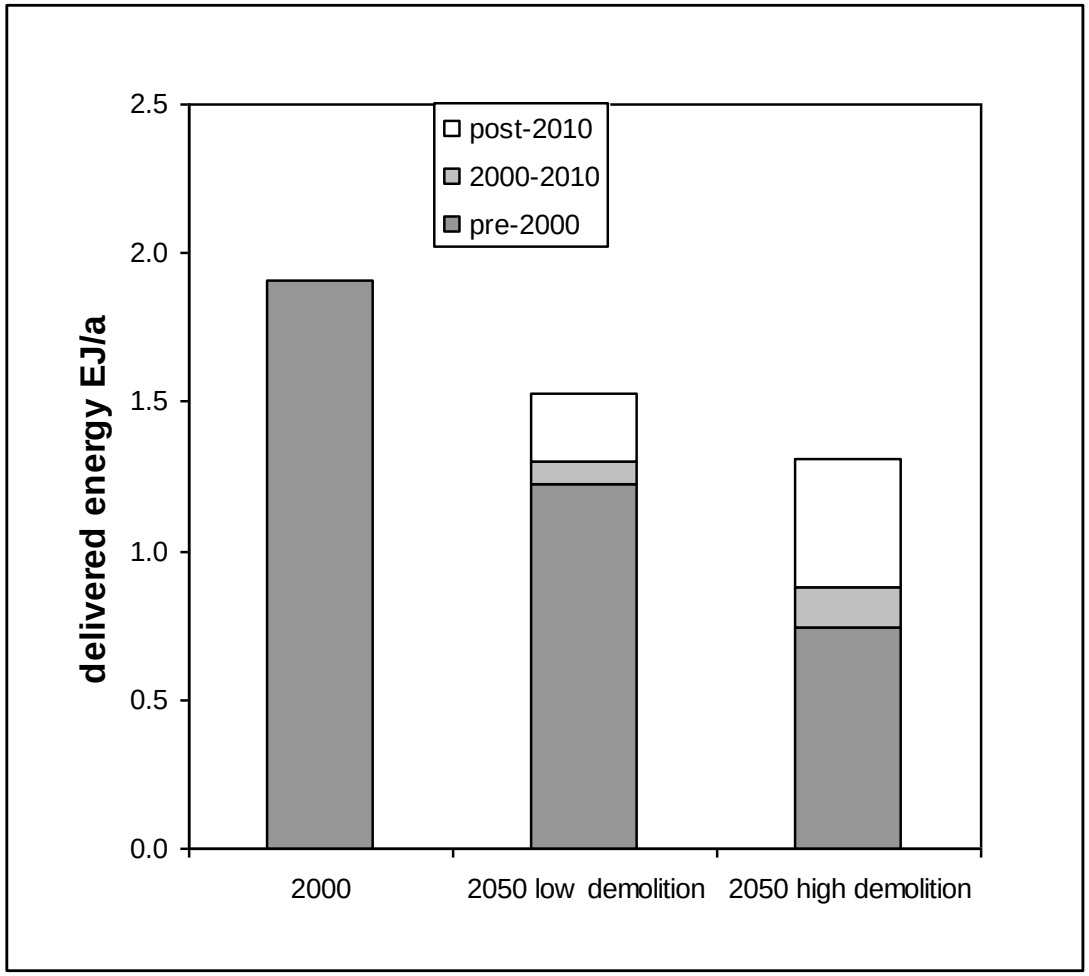


the basic scenario

in 2050:

- electricity 0.2 kg (CO_2)/kWh (= natural gas)
- delivered heat 0.1 kg (CO_2)/kWh
- 40% reduction in delivered energy for heating in pre 2000 dwellings
- electricity use for lights & appliances at 2000 level
- low demolition rate 15,000 per year
- high demolition rate 200,000 per year

delivered energy



Police raid home of Blunkett Bobby after infrared helicopter mistook bad insulation for cannabis factory

By David Wilkes
Last updated at 1:12 AM on 31st July 2008

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When the police helicopter's infrared camera detected something unusual, officers were quick to act.

The building was 'bright' – sometimes an indication that warm lamps are being used to help cultivate a drug crop.

Scanning the monitor an officer said: 'There's a house that's doing a glow in the dark. – We thinking it might be cannabis related.'

Two colleagues were duly dispatched to the property – only to find it was the home of police community support officer Zally Hussyn.

The glow had been caused by poor roof insulation and not, as they had suspected, the powerful lights typically used in drug factories.

Ms Hussyn, 45, has told how she was horrified when the officers, who recognised her from work, entered to search her £400,000 detached home in Cambourne, Cambridgeshire.

'When I saw the squad car I thought it was colleagues just popping in for a cup of tea,' the mother of five said. 'They said if I hadn't been in they'd have to have broken the door down.'

Police use helicopter heat monitoring to spot houses where cannabis is grown indoors under light that generates a bright white blaze on infrared cameras.

Shocked: Zally Hussyn at her home in Cambridge which was mistakenly raided by colleagues

Giveaway: Steve and Zally's home on infrared camera shows massive amounts of heat coming out of the roof

Ray of light: The couple's house can clearly be seen in the camera's view finder

The officers showed her the helicopter DVD that had aroused their suspicions. But a search of the four-year-old house only found shoddy insulation.

Ms Hussyn, who has been a PCSO, otherwise known as a Blunkett's bobby, since March 2007, said: 'I'm so embarrassed.'

A Cambridgeshire Police spokesman confirmed the heat source was traced to poor loft insulation.

A real cannabis factory, discovered at a house in Dagenham, East London

Ms Hussyn and her husband Steve, a 49-year-old garage owner, have lived in the five-bedroom house for less than 18 months. The incident has fuelled their anger about what they claim is the house's poor design.

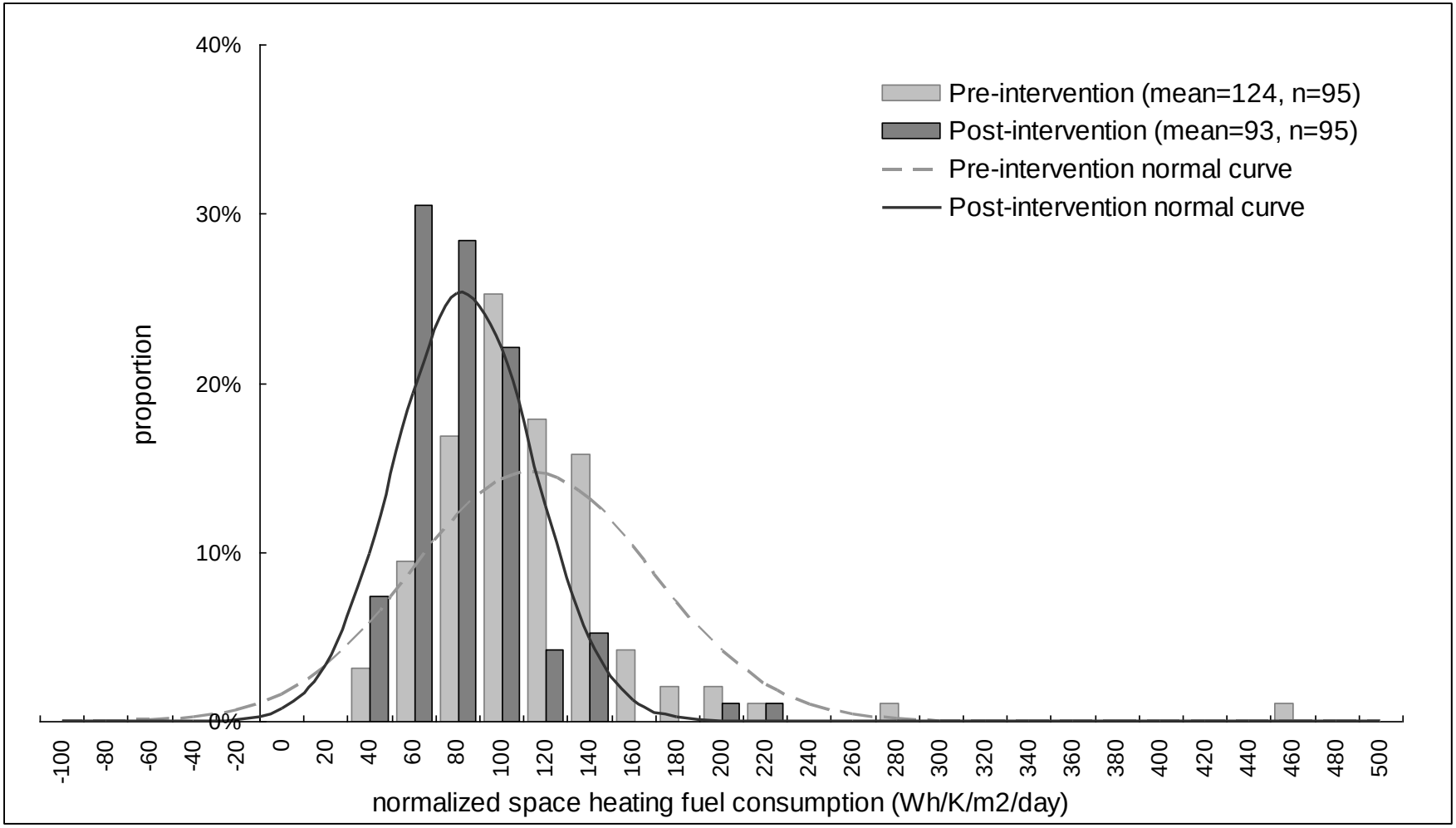
'These houses are meant to be environmentally and economically friendly but last year's gas bill was £1,000. I feel I've been ripped off,' she added.

David Bell, managing director of builders David Wilson Homes South Midlands, said he had been contacted by Ms Hussyn regarding concerns over energy efficiency.

After conducting additional investigations the firm 'found the home complies with all the relevant standards'.

TECHNOLOGY IS THE ANSWER..!
NOW WHAT'S THE QUESTION ?

Modelled


Pre-intervention (mean=124, n=95)
Post-intervention (mean=93, n=95)
Pre-intervention normal curve
Post-intervention normal curve
proportion
40%
30%
20%
10%
0%
-100
-80
-60
-40
-20
0
20
40
60
80
100
120
140
160
180
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220
240
260
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320
340
360
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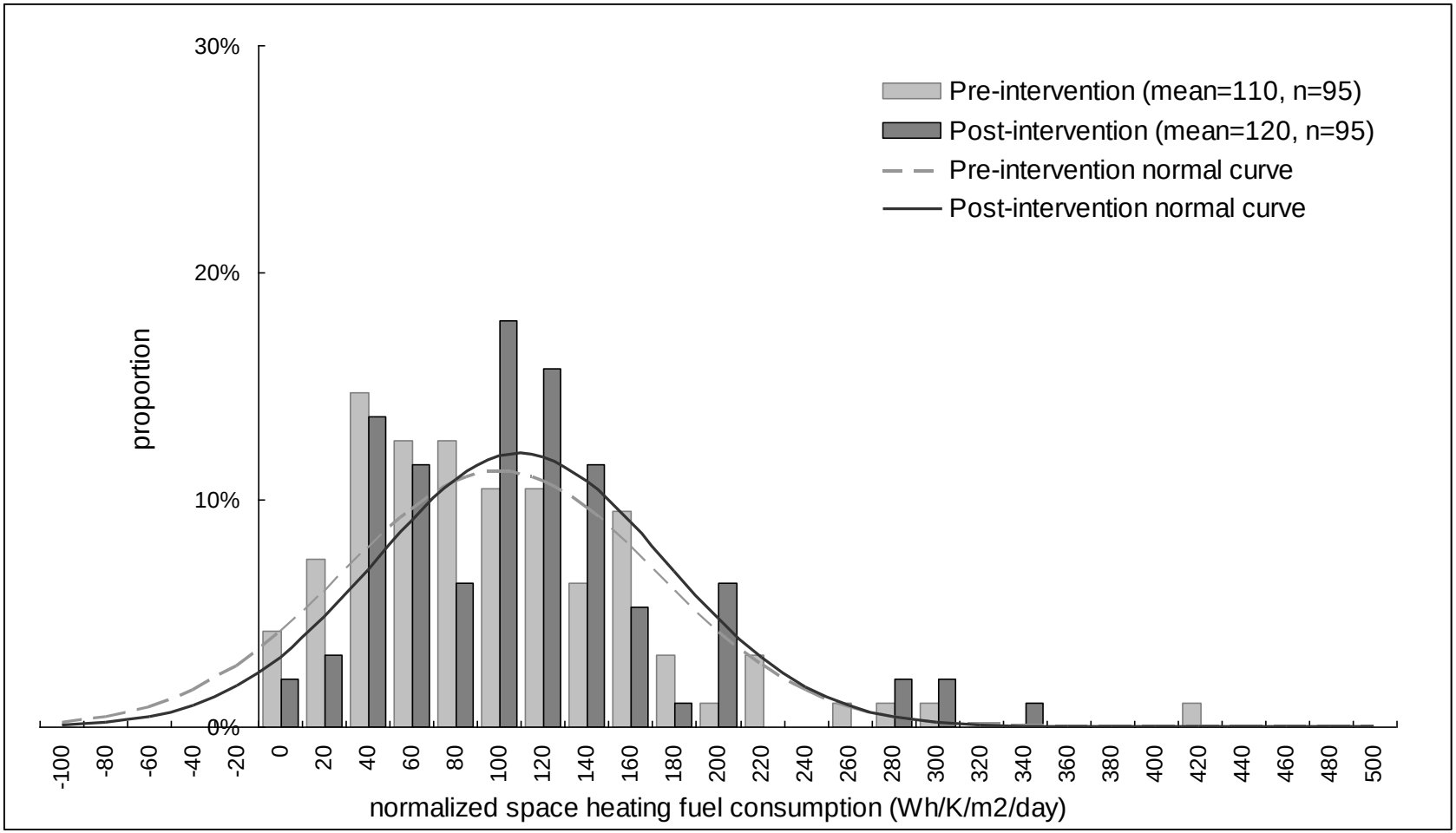
420
440
460
480
500
normalized space heating fuel consumption (Wh/K/m2/day)

(B) Monitored


30%
20%
10%
0%
proportion
Pre-intervention (mean=110, n=95)
Post-intervention (mean=120, n=95)
Pre-intervention normal curve
Post-intervention normal curve
-100
-80
-60
-40
-20
0
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normalized space heating fuel consumption (Wh/K/m2/day)