SuperHome truths about domestic energy efficiency

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Motivation for reducing CO_2 emissions

Global surface temperature will continue to increase until at least the mid-century … Global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in CO_2 and other greenhouse gas emissions occur in the coming decades. (Intergovernmental Panel on Climate Change)

The Climate Change Act (2008) established a target for the UK to reduce its greenhouse-gas (GHG) emissions by at least 80% from 1990 levels by 2050, as an appropriate UK contribution to global reductions consistent with limiting global temperature rise to as little as possible above 2°C. In 2019, Parliament changed it; the target is now to reduce emissions by 2050 by at least 100% relative to 1990.

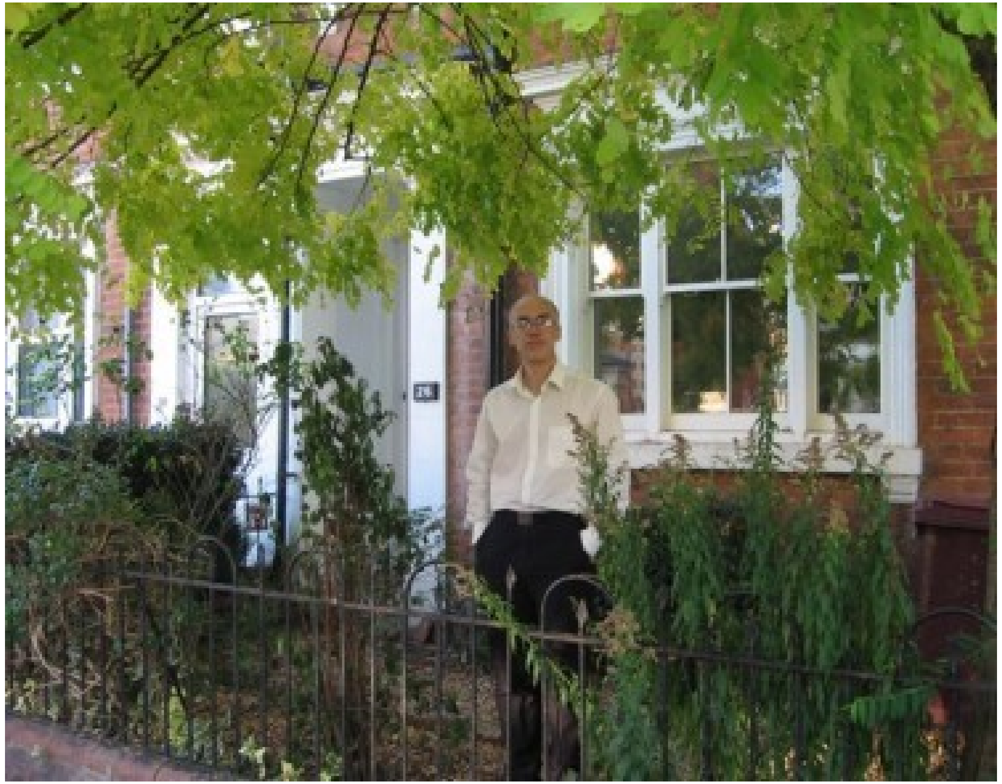
100% reduction could mean zero GHG emissions, but in practice it's more likely to mean "**net zero**".

[This] will deliver on the commitment that the UK made by signing the Paris Agreement. It is achievable with known technologies, alongside improvements in people's lives. However, this is only possible if clear, stable and well-designed policies to reduce emissions further are introduced across the economy without delay. Current policy is insufficient for even the existing targets. (Committee on Climate Change)

UK GHG emissions in 2021 were 47% below 1990.

Residential emissions give 20% of the UK total, residential use of grid electricity ~10%.

Pioneer SuperHome 134 (of 200): Reading Eastern Avenue
Semi-detached, built 1873, four floors counting basement



Pioneer SuperHomes are old buildings refurbished by their present owners to reduce their CO_2 emissions by at least 60%, through energy efficiency and domestic renewable energy production.

I participated in five SuperHomes open days, tours for 20-30 people each time.

View from the street

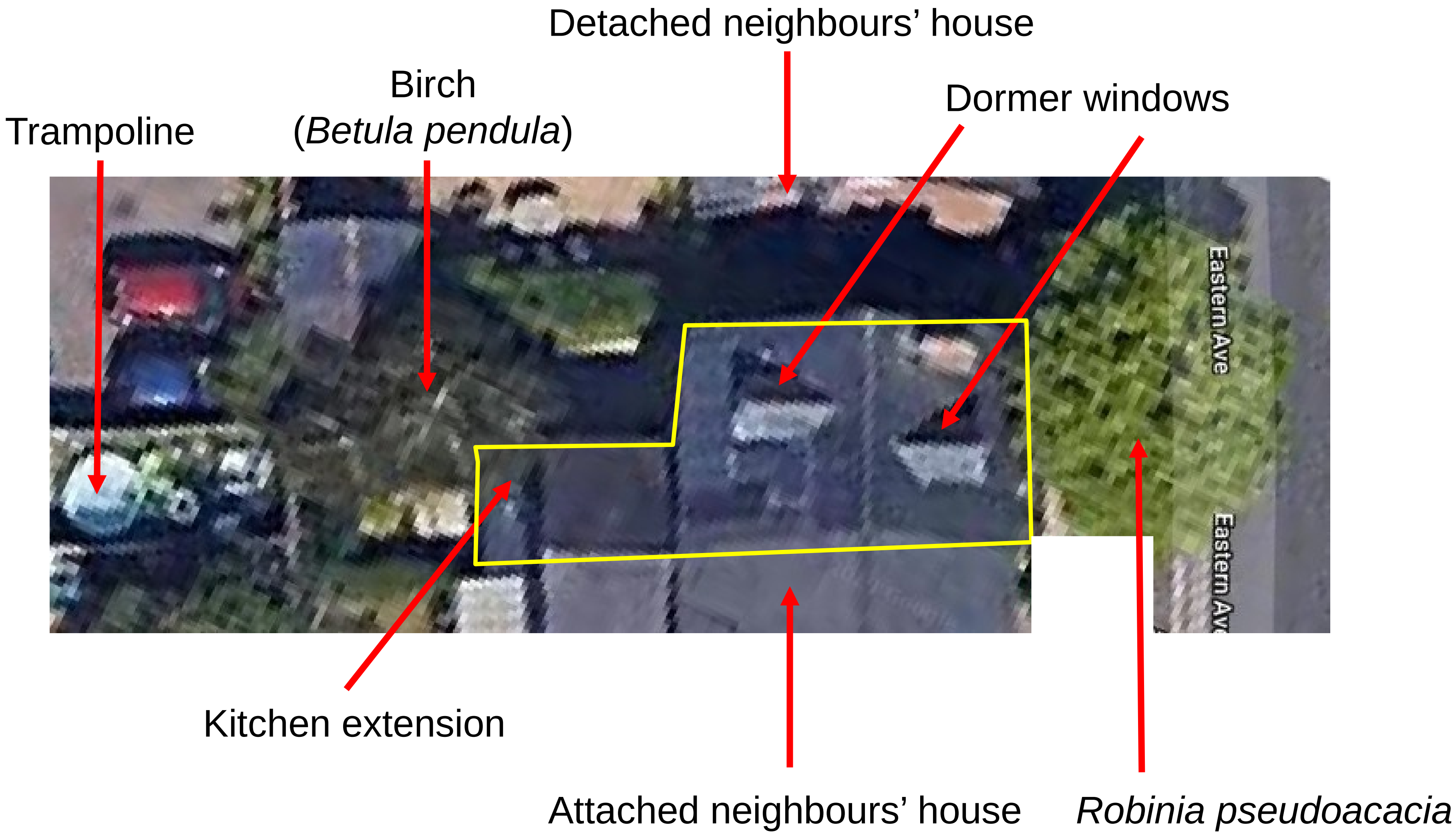
Attached neighbours' house

Green Party election poster

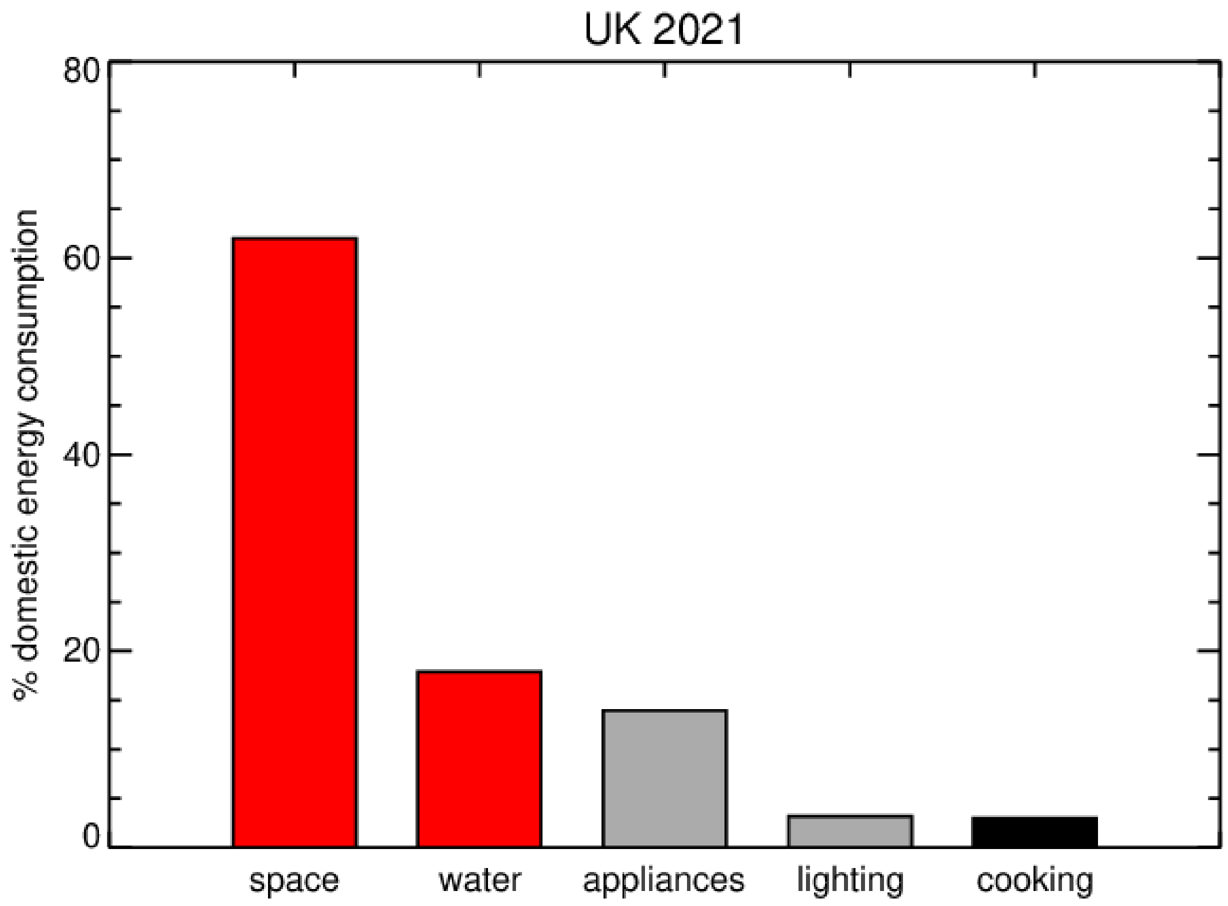
Detached neighbours' house

Robinia pseudoacacia

View from satellite



Effective ways to reduce domestic CO_2 emissions



Reduce space and water heating

Replace heating by gas, coal or oil (fossil fuel) with a heat pump

Buy or collect your own green energy

Use efficient electrical appliances (especially wet and cold appliances)

Don’t be distracted by the myth that “Every little helps.” If everyone does a little, we’ll achieve only a little. We must do a lot. What’s required are big changes in demand and in supply. (David Mackay)

(1) We can reduce UK energy consumption if we **Insulate Britain** by improving our *u*-values — smaller is better

When there is a temperature difference ΔT across a thickness h (m) of a material which has a thermal conductivity κ (W m^{-1} K^{-1}), the heat flux (W m^{-2}) through the layer is

$$H = \kappa \Delta T / h = u \, \Delta T,$$

where

$$u = \kappa / h$$

(in W m^{-2} K^{-1}) is a property of the insulating layer.

For example, with ΔT = 10 K and u = 2 W m^{-2} K^{-1}, the heat flux is 20 W m^{-2}. If the layer has an area of 100 m^2, the heat flux is 2 kW. If this goes on all year round, the energy loss is 17,500 kWh.

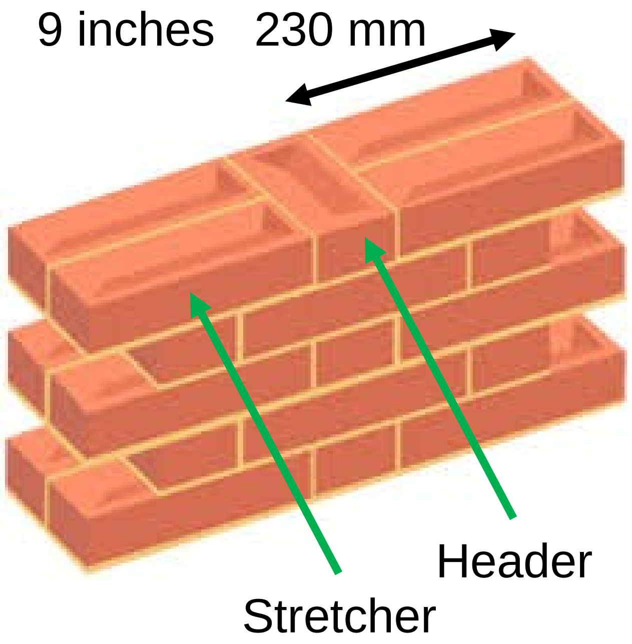
Top-down approach — Roofs, walls, floors

The current building regulations for conservation of fuel and power (Part L, 2021 edition) specify u = 0.11 W m^{-2} K^{-1} for the roof of a new notional dwelling.

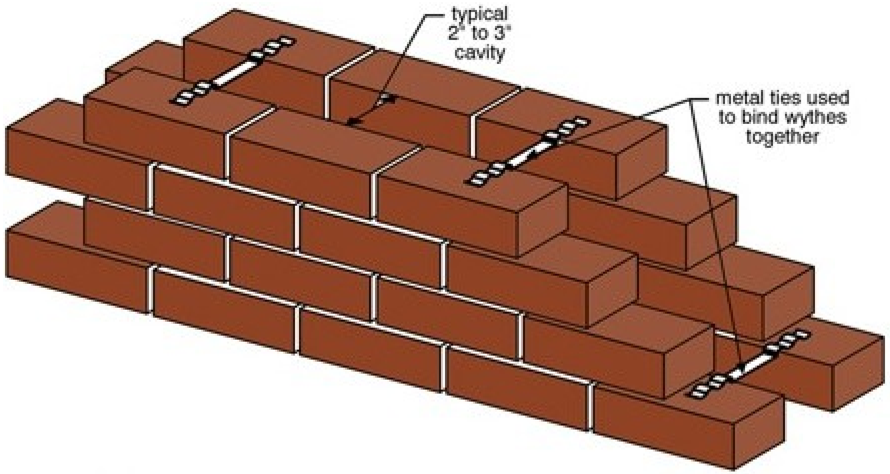
Polyisocyanurate (PIR) e.g. Celotex has κ = 0.023 W m^{-1} K^{-1} so h = 0.023/0.11 = 0.21 m
Mineral wool 0.035 W m^{-1} K^{-1} so h = 0.32 m
Glass 1 W m^{-1} K^{-1}
Copper 400 W m^{-1} K^{-1}
Diamond 2000 W m^{-1} K^{-1}

Walls

Solid wall



Cavity wall



8.5M (about 1/3) of the houses in the UK have solid walls, of which 91% have no wall insulation.

Exterior insulation of gable-end wall by creating a cavity

Loft and ceiling insulated

Roof extended

Window surround recreated

190 mm PIR, u=0.12 W m^{-2} K^{-1}, cf. Part L 0.18

Exterior insulation of gable-end wall by creating a cavity

Conduit from photovoltaic panels

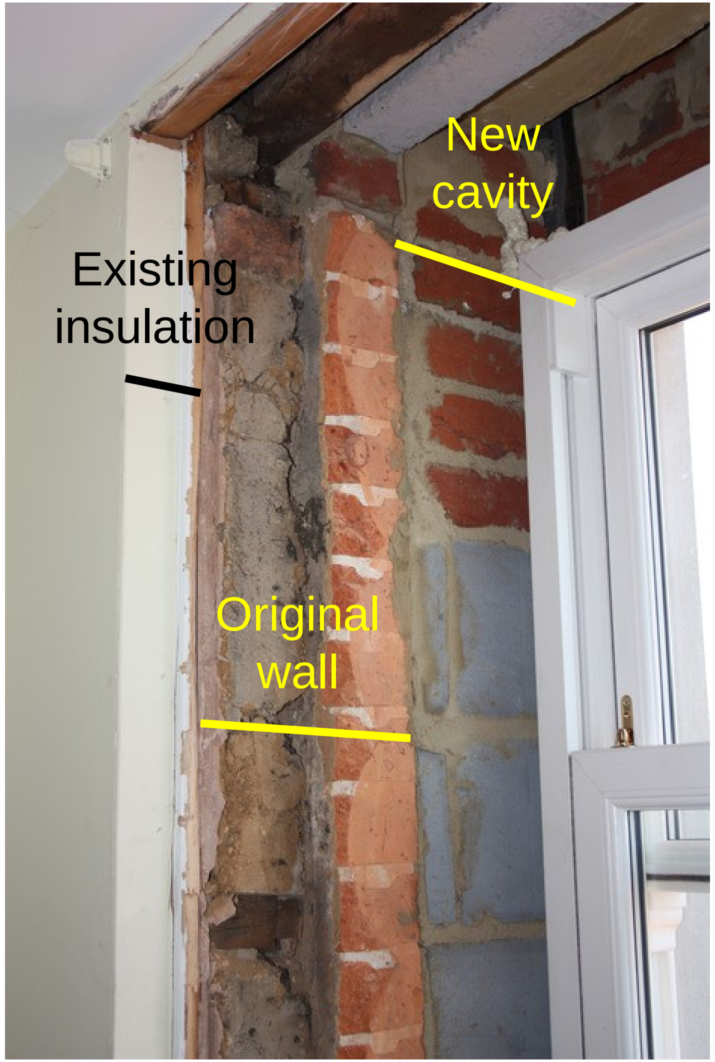
Pipes to air source heat pump

Double-glazed
wooden sash window
u=1.9 W m^{-2} K^{-1}

Fanned balanced boiler flue

Boiler condensate outflow pipe

Exterior insulation of gable-end wall by creating a cavity



New double-glazed uPVC sash window, u=1.5 W m^{-2} K^{-1}

Interior insulation of other external walls

New wood panelling   Original shutter box

100 mm PIR, u=0.23 W m^{-2} K^{-1}

New plasterboard wall

Kitchen extension

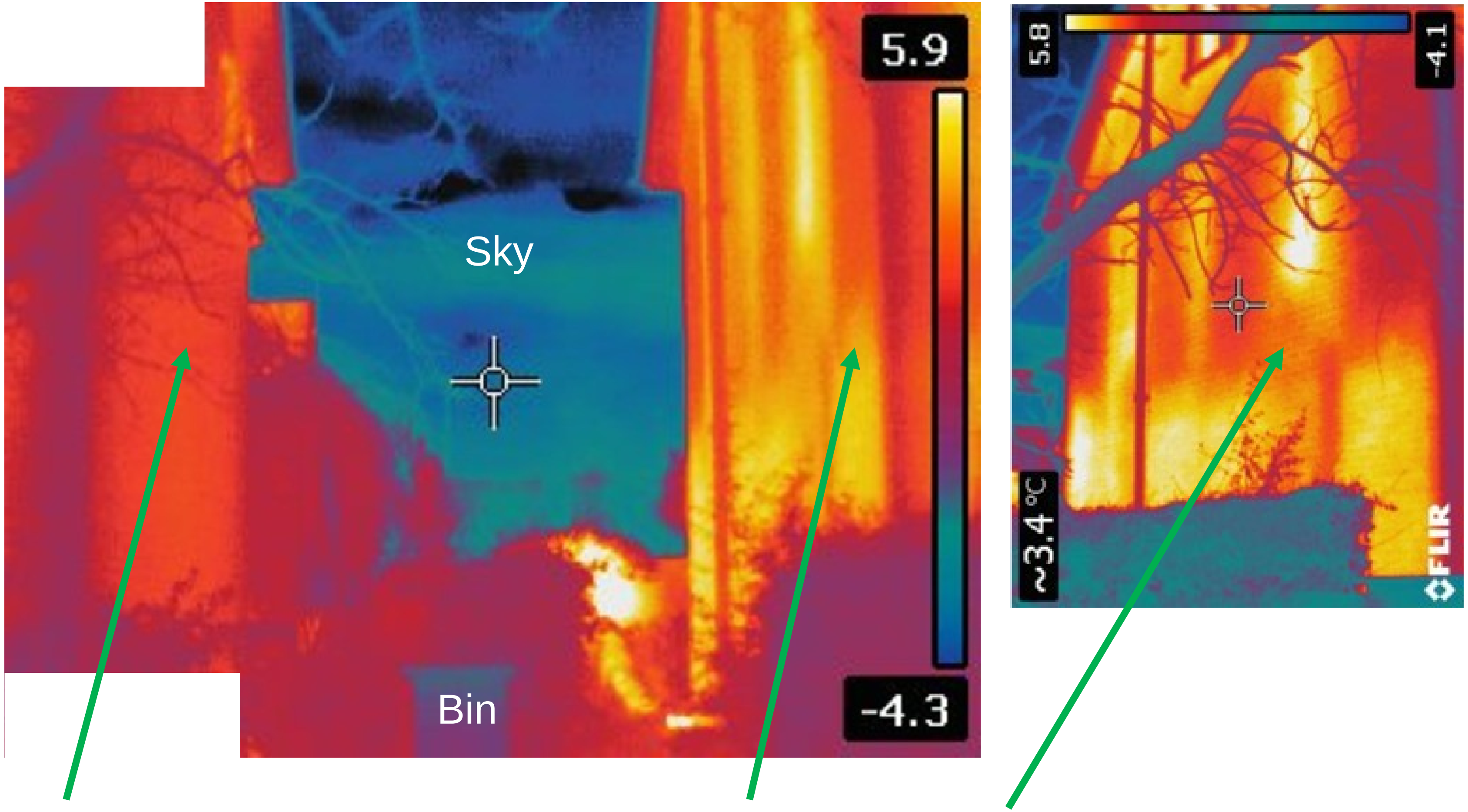
Roof 0.12 W m^{-2} K^{-1} cf. Part L 0.11

Cavity wall 0.17 W m^{-2} K^{-1} cf. Part L 0.18

Door 0.7 W m^{-2} K^{-1} cf. Part L 1.2

Thermal view of back of house and extension roof

Thermal view of side of house

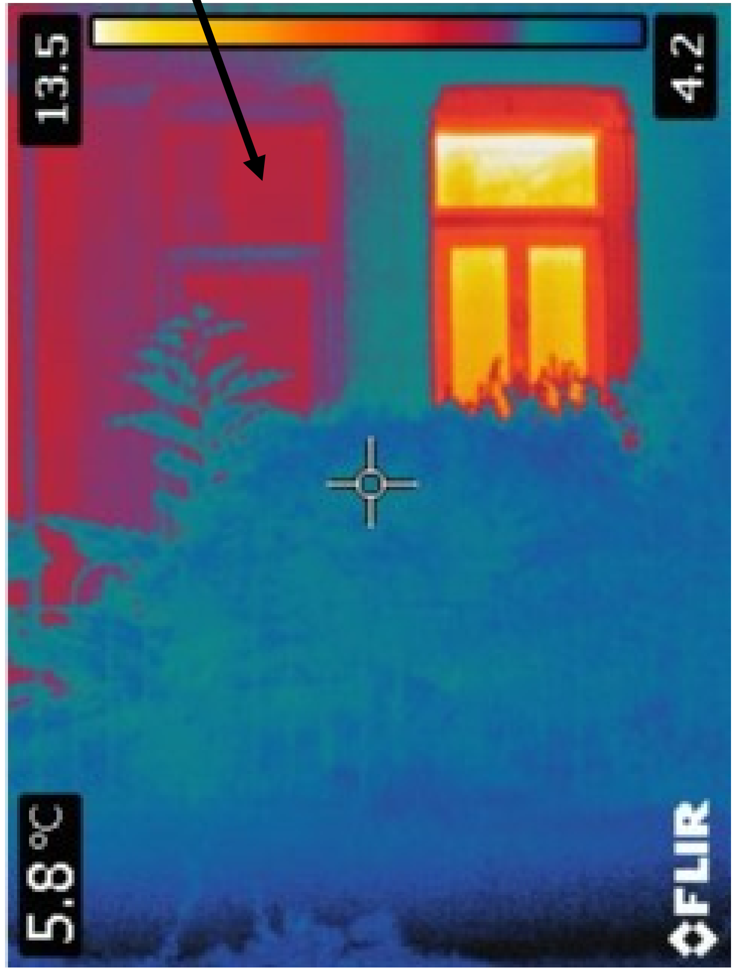


Side wall of my house

Side wall of detached neighbours' house

Front door

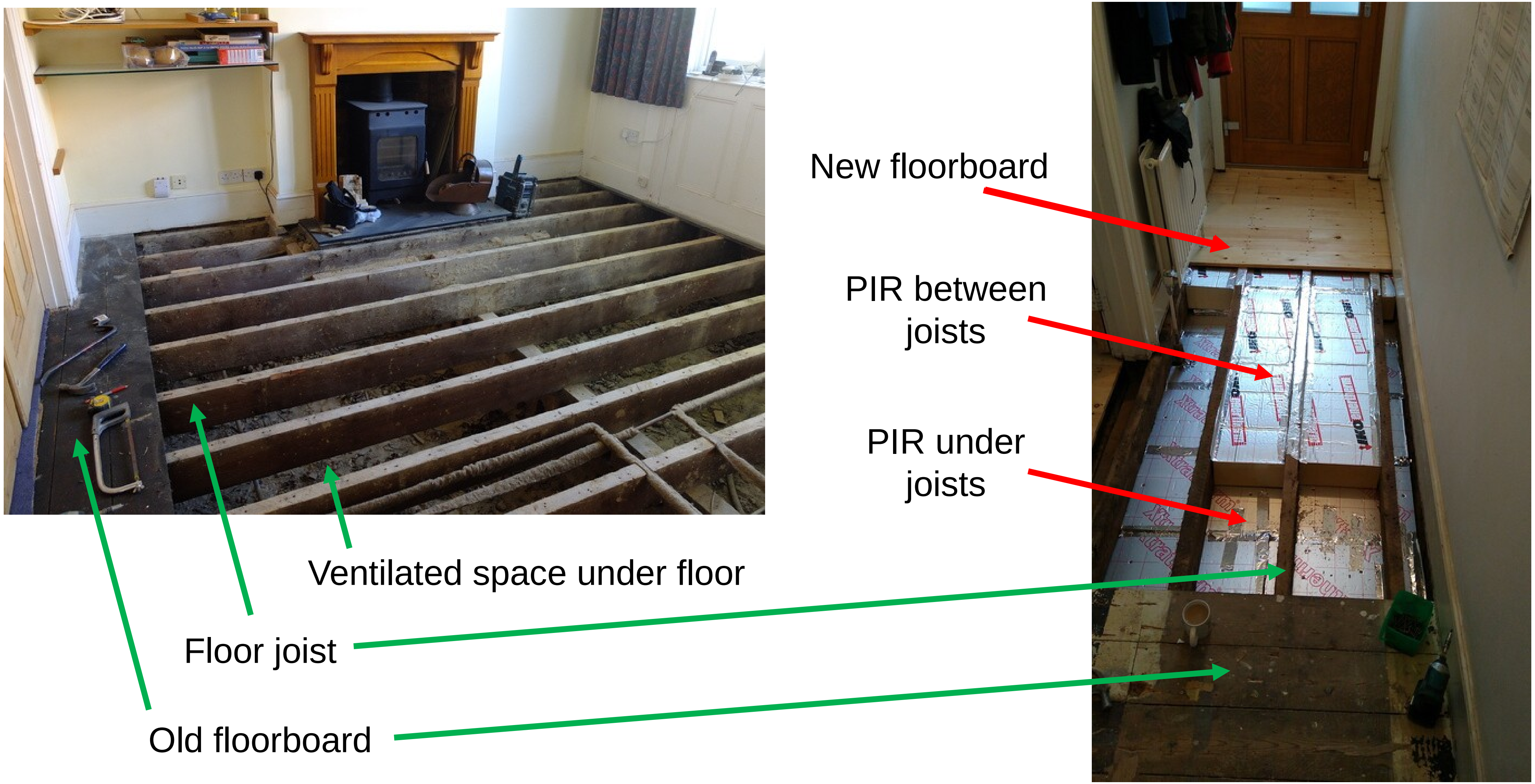
Attached neighbours’ front door



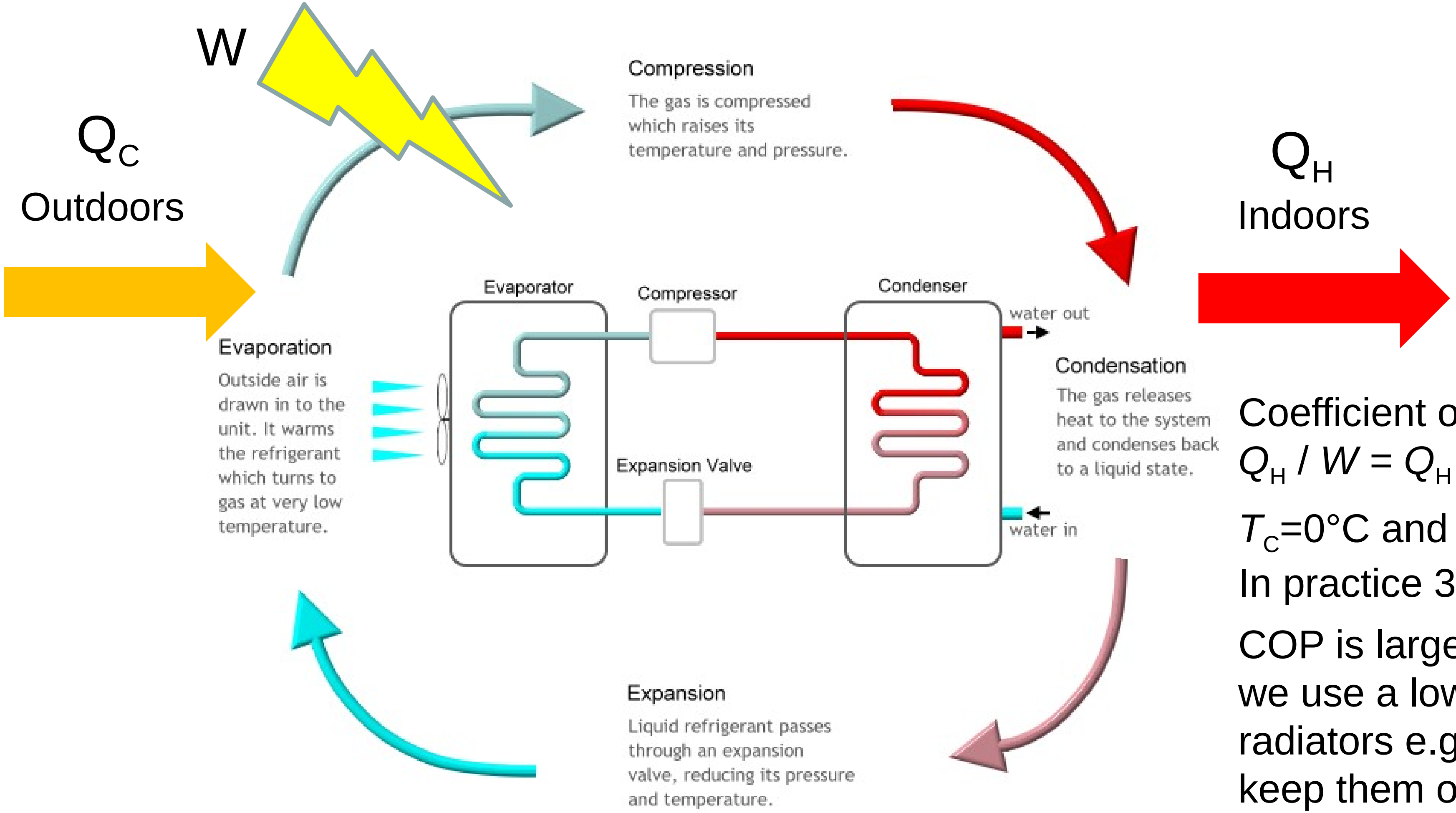
Our new front door

1.0 W m^{-2} K^{-1} cf. Part L 1.0

Insulating under suspended floor



(2) Air source heat pump (ASHP) gives you **bonus energy**



$Q_H = Q_C + W$

$Q_C/Q_H = T_C/T_H$

Coefficient of performance (COP)

$Q_H\ /\ W = Q_H\ /\ (Q_H - Q_C) = T_H\ /\ \Delta T$

T_C=0°C and T_H=40°C give COP=7.8

In practice 3 is a good COP

COP is larger if ΔT is smaller, so we use a low flow temperature to radiators e.g. 40°C, not 60°C, and keep them on for longer. This plan depends on good insulation.

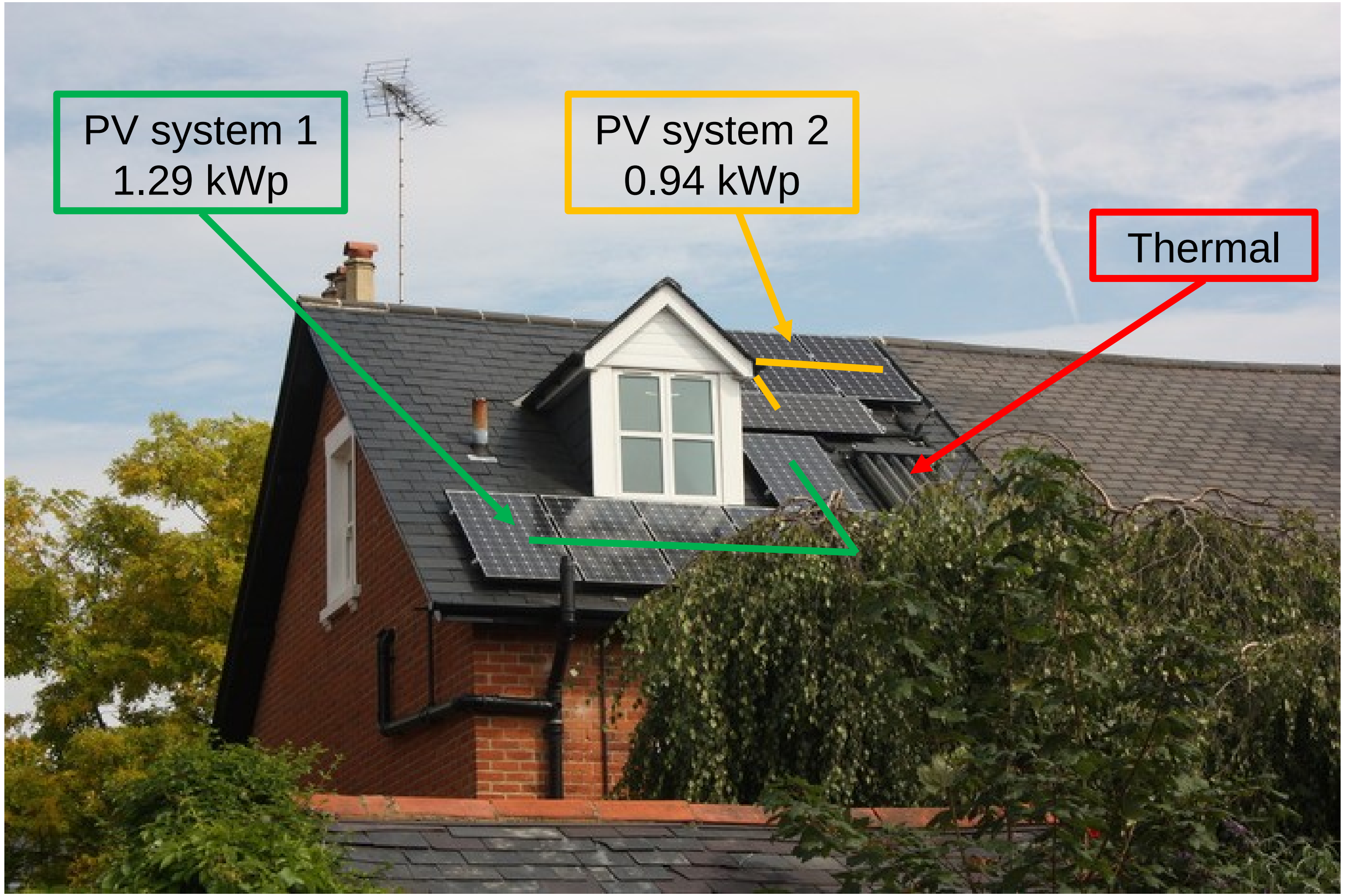
Air source heat pump (ASHP)

(3) **Free green energy** from the sun

Solar photovoltaic panel (electricity)

Solar thermal panel (hot water)

Solar energy

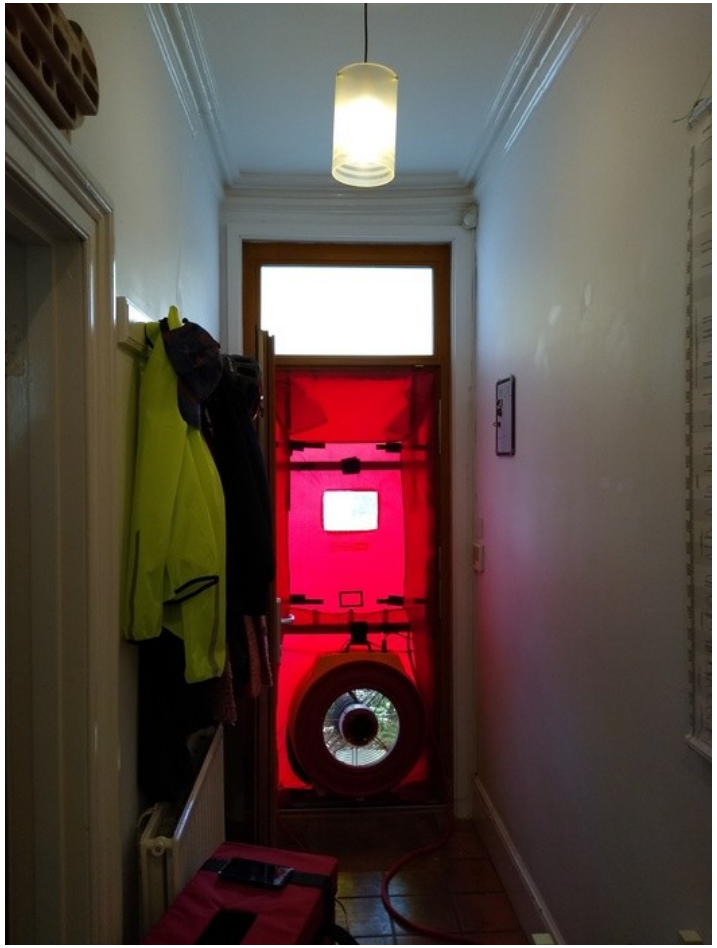


Air exchange compared with conduction

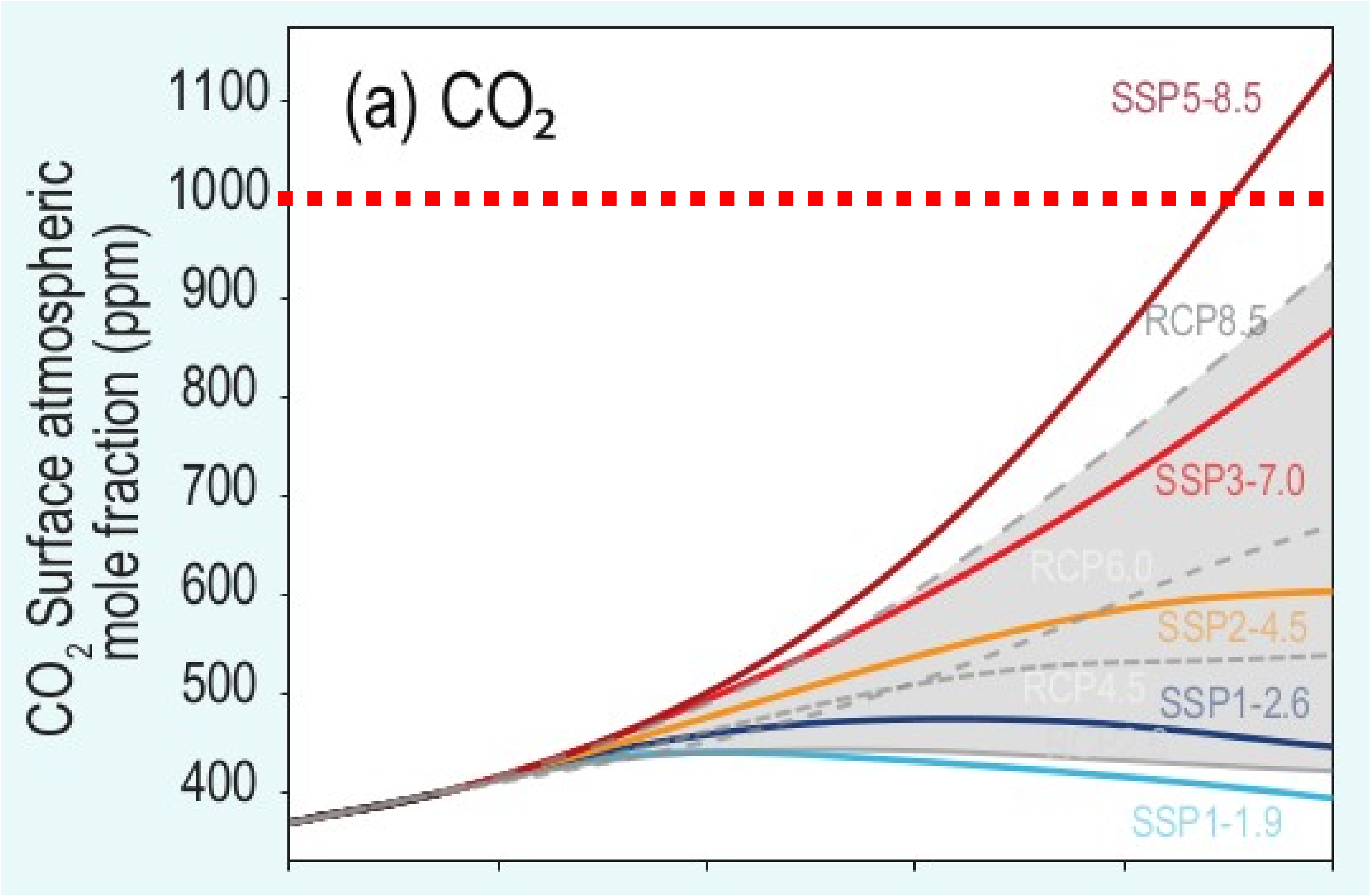
Part L new dwellings leakage 5 m^3 h^{-1} m^{-2} at 50 Pa, my house is 9.0.
House envelope area A = 372 m^2, internal volume V = 400 m^3.
Hence 8 air changes per hour ACPH cf. Passivhaus 0.6 ACPH.

If the volume V of air is changed with frequency n, each time with fraction f of the heat being lost, and the temperature difference between inside and outside is ΔT, the rate of heating (W) required to compensate is $H = V\, n\, f\, C_p\, \Delta T$, where C_p = 1.2 kJ m^{-3} K^{-1}.
We can consider an equivalent $u = H/(A\, \Delta T) = n\, f\, C_p\, V/A$.
With n = 8 hr^{-1} and f = 1, u = 2.9 W m^{-2} K^{-1},
similar to the conduction loss if the house were not insulated.

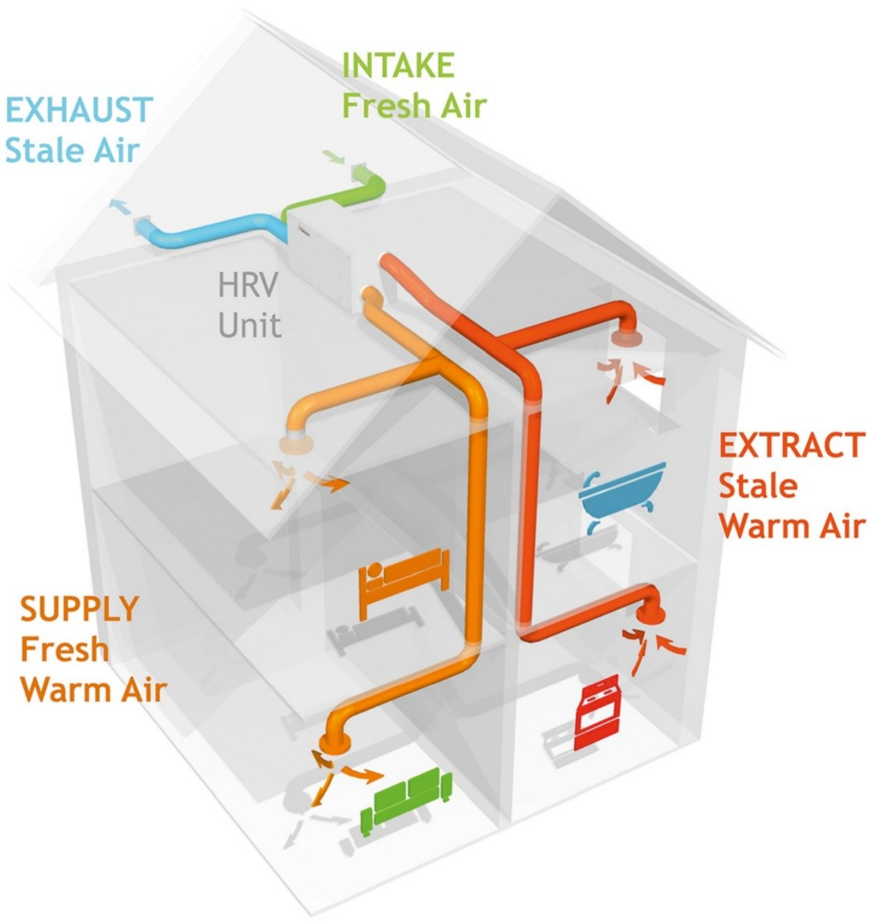
But is n really that large in normal use of the house, I wonder.
I observe that with just me in the house and all the windows closed, the CO_2 concentration indoors is ~200 ppm higher than outdoors.
I calculate that if I produce 2000 kcal by respiring glucose,
I raise the partial pressure of CO_2 indoors by ~1000 ppm.
Hence I infer the air is changed 5 times per day, 0.2 ACPH. Uh?

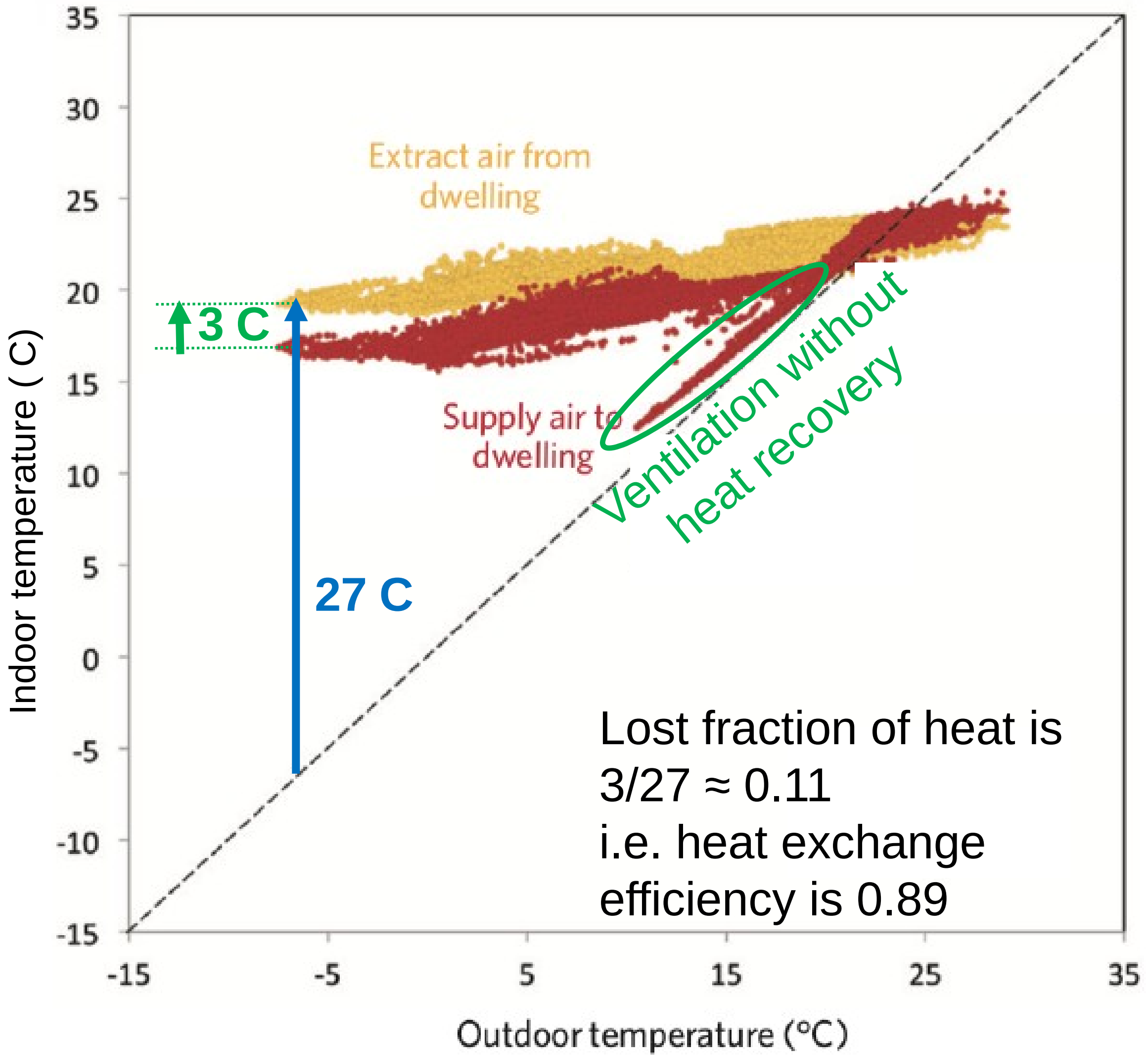


Humans suffer significant cognitive impairment at 1000 ppm CO_2

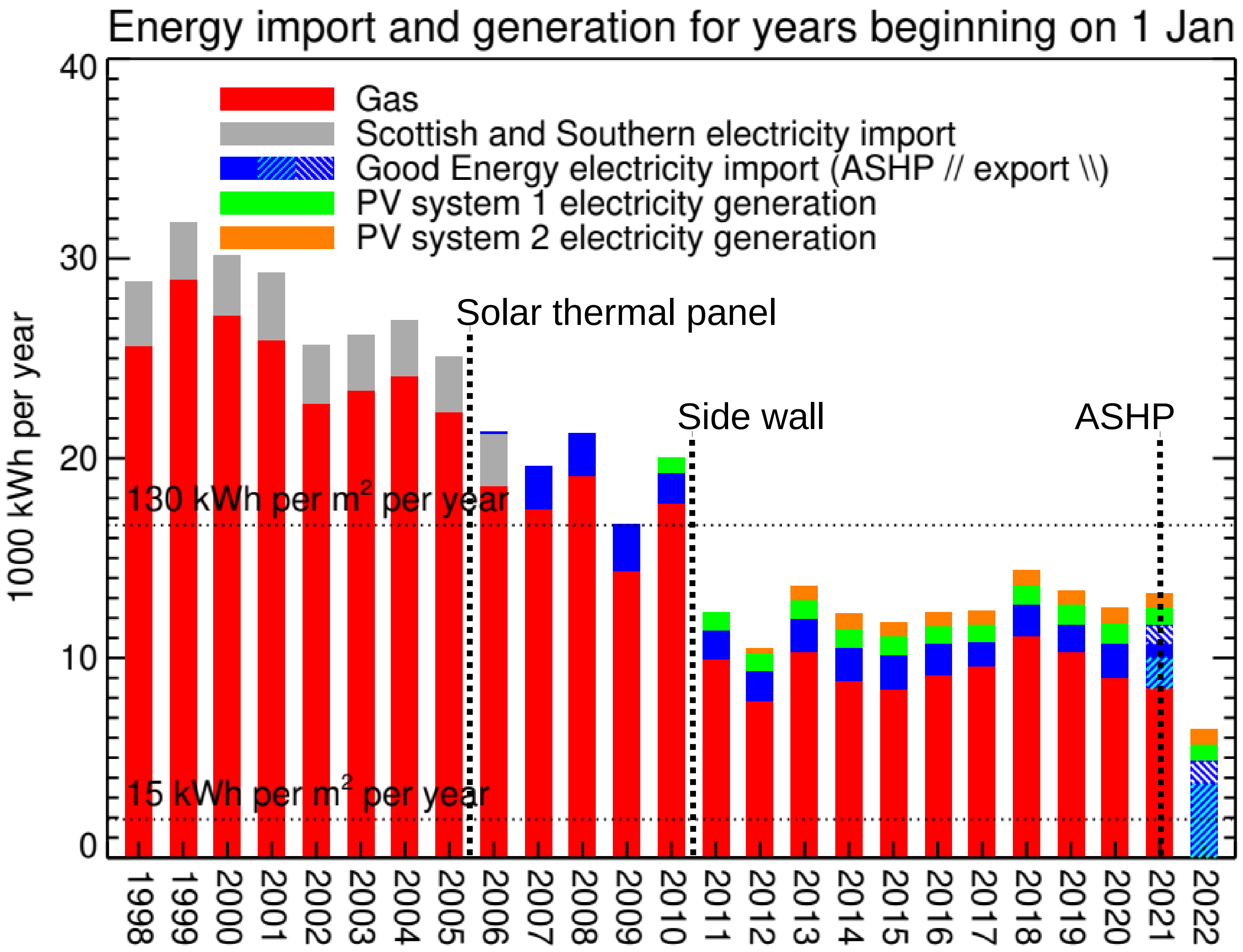


Mechanical ventilation with heat recovery (MVHR)





Lost fraction of heat is
3/27 ≈ 0.11
i.e. heat exchange
efficiency is 0.89



Energy import and generation for years beginning on 1 Jan
Gas
Scottish and Southern electricity import
Good Energy electricity import (ASHP // export \\)
PV system 1 electricity generation
PV system 2 electricity generation
Solar thermal panel
Side wall
ASHP
130 kWh per m² per year
15 kWh per m² per year
1000 kWh per year
0
10
20
30
40
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
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2012
2013
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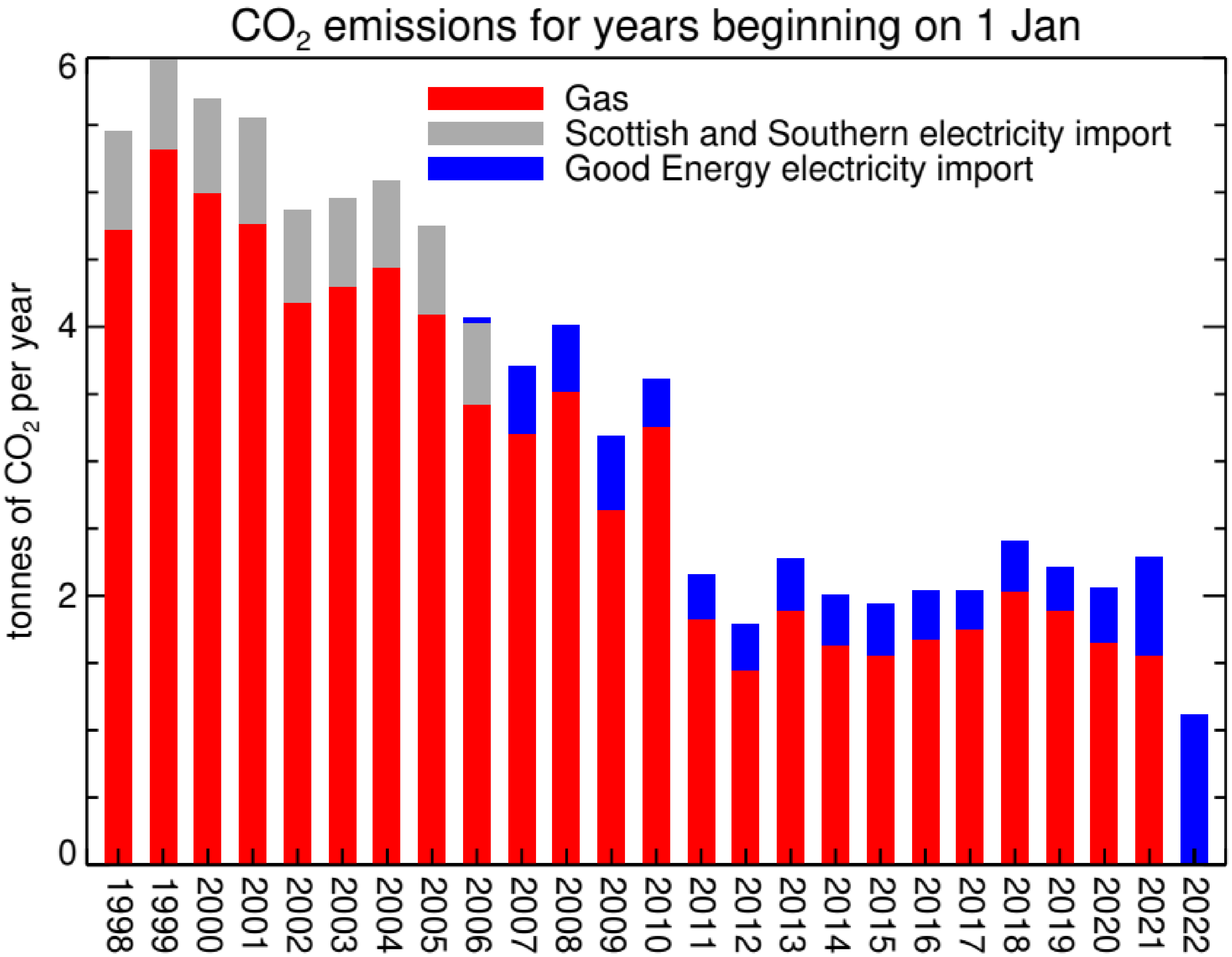
2016
2017
2018
2019
2020
2021
2022



CO2 emissions for years beginning on 1 Jan
Gas
Scottish and Southern electricity import
Good Energy electricity import
tonnes of CO2 per year
0
2
4
6
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022

Conclusions

30% of UK CO_2 emissions come from domestic energy consumption.

Many houses in the UK are old.

It is possible to eliminate CO_2 emissions from an old house, by:

Wall insulation (in the cavity if any, otherwise inside or outside)

Double or triple glazing

Air source, ground source or water source heat pump (which give a thermodynamic advantage), hydrogen or biomass boiler

Solar electricity generation and solar water heating

Importing the remaining energy requirement from renewable sources