How and when are UK homes heated: from measurement to modelling.

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Bottom up stock modelling

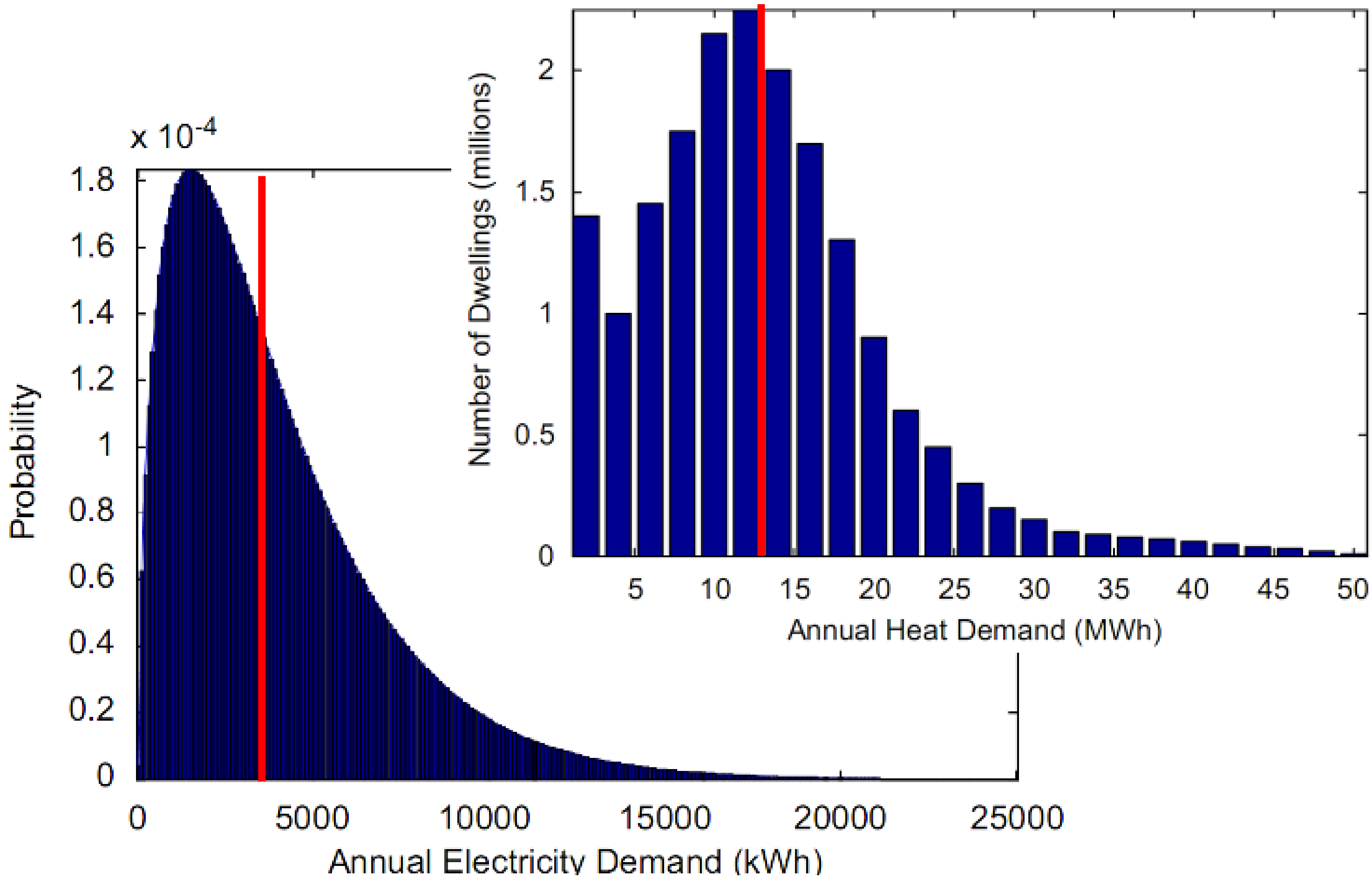
The stock average/totals

- What is the total (heating) energy demand of a stock of homes?
- How might this alter with refurbishment, behavioural change, climate change?
- What is the optimal cost/benefit strategy?

The profile of demands

- The extremes of demand shape supply infrastructure.
- What is the aggregated energy demand profile?
- What affect do interventions have on aggregated energy demand profiles?

The variations in energy demand of homes in England



A.D. Hawkes & M.A. Leach (2008) Energy Policy 36 2973–2982

The archetype approach

- Divide the stock into a finite number of dwelling archetypes, and associate ‘energy systems’.
- Add occupancy profiles to each archetype.
- Predict the energy demands (static or dynamic model).
- Combine the results in proportion to the number of each archetype in the stock.

- Change description of archetype.
- New total energy demand.
- Thus predicted energy, CO_2, etc. savings.

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Domestic Buildings in the UK: some numbers

- There are about 26 million homes in the UK, 21 million in England.
- Average of 2.47 persons per dwelling.
- Average floor area 84m^2.
- Around 78% gas central heating.
- The world's oldest housing stock?
- A few archetypes 'describe' most dwellings

The CDEM model: House archetype category combinations

Built form categories	Dwelling age band categories
End terrace Mid terrace Semi detached Detached	pre 1850, 1851 to 1899, 1900 to 1918, 1919 to 1944, 1945 to 1964, 1965 to 1974, 1975 to 1980, 1980 to 1990, 1991 to 2001
Flat: purpose built	1900 to 1918, 1919 to 1944, 1945 to 1964, 1965 to 1974, 1975 to 1980, 1980 to 1990, 1991 to 2001
Flat: other (converted or in commercial building)	pre 1850, 1851 to 1899, 1900 to 1918, 1919 to 1944

- 47 archetypes.
- Within each type weighted efficiencies depending on proportion of different methods of heating, cooking, etc.
- Weighted U-values based on proportions insulated, not insulated etc.

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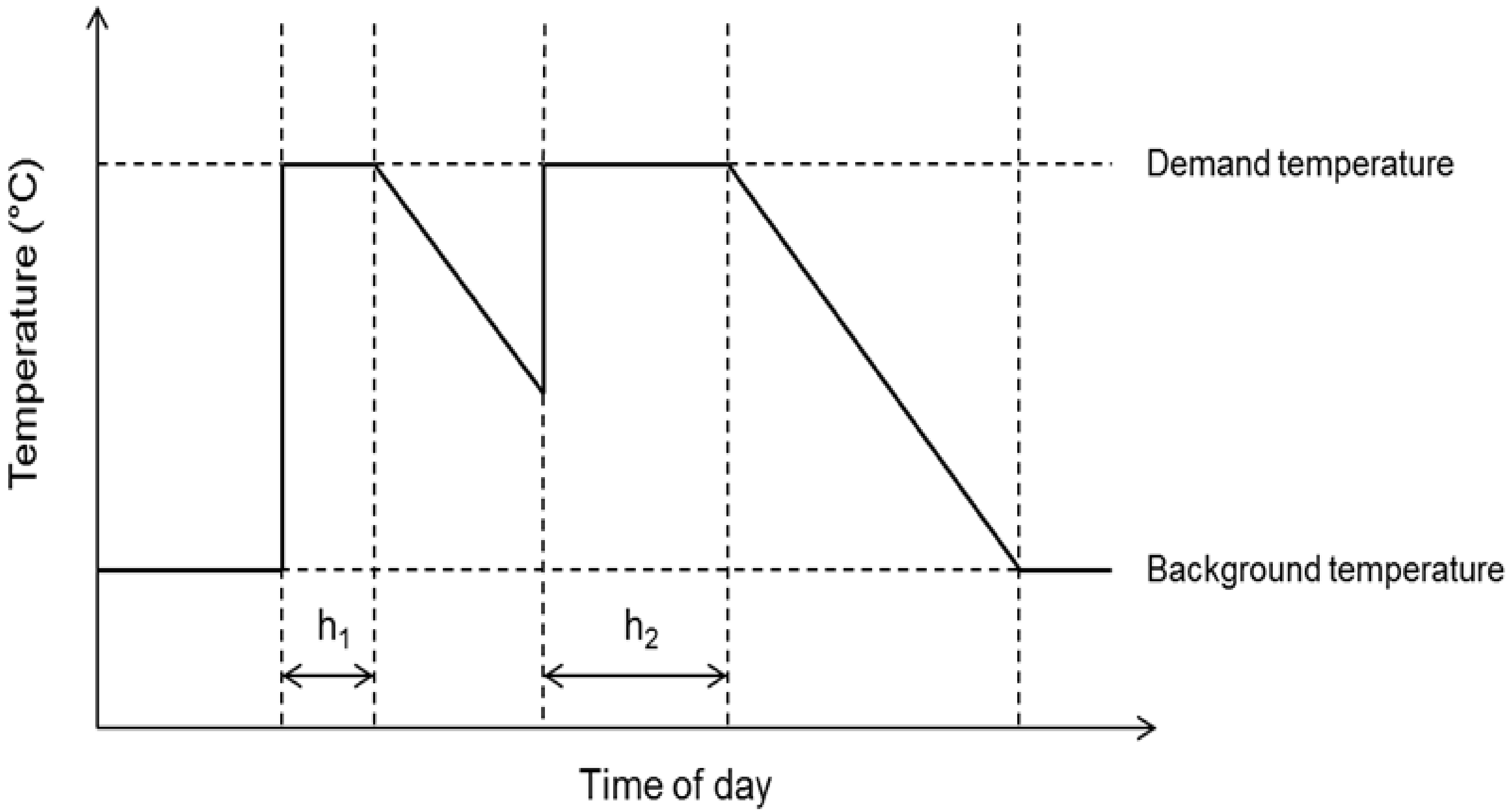
BREDEM and SAP-based models' assumed heating regimen.



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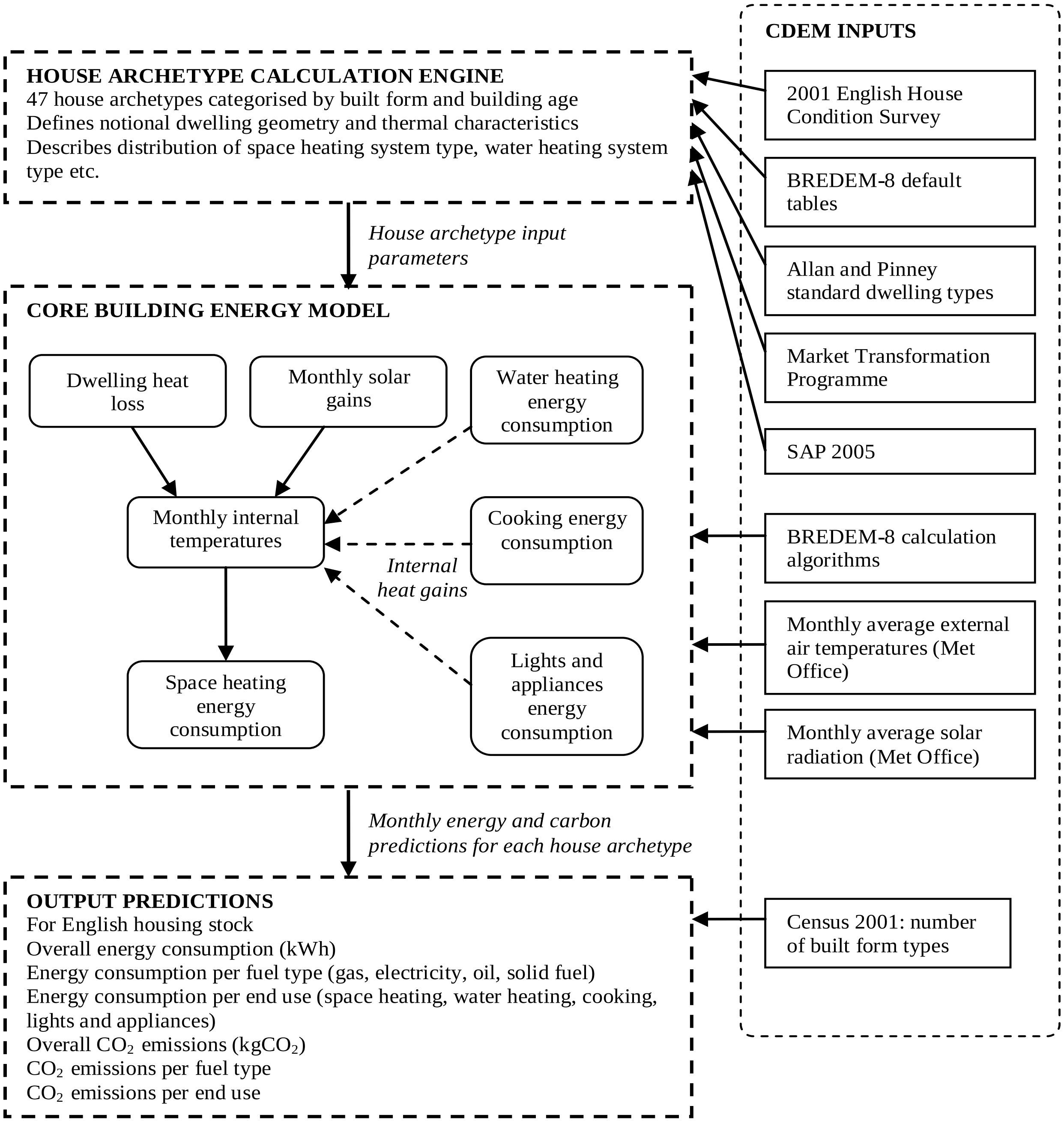

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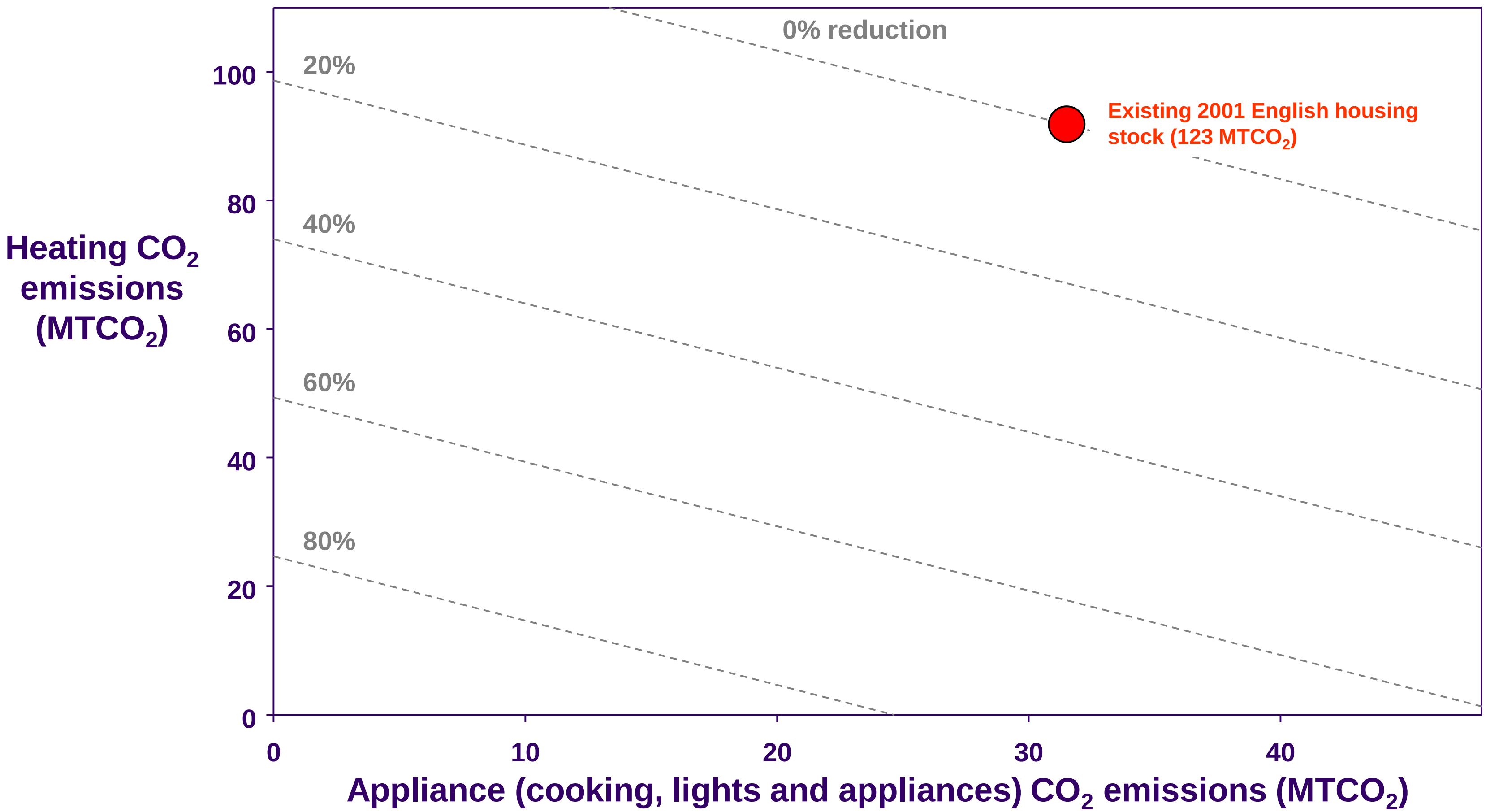
Energy efficiency predictions: 2001 English housing stock



- Based on 1971 to 2000 average climate data

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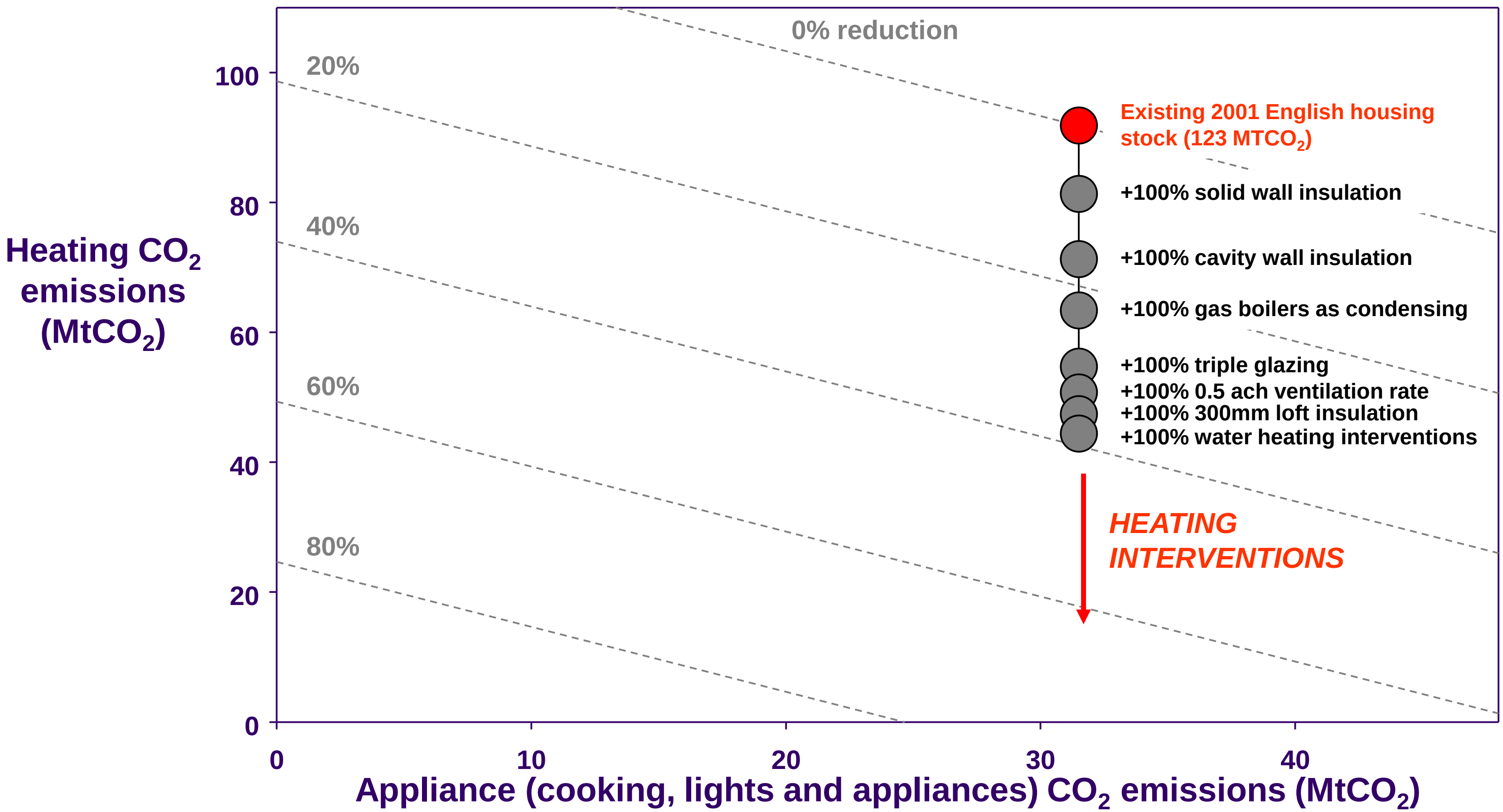

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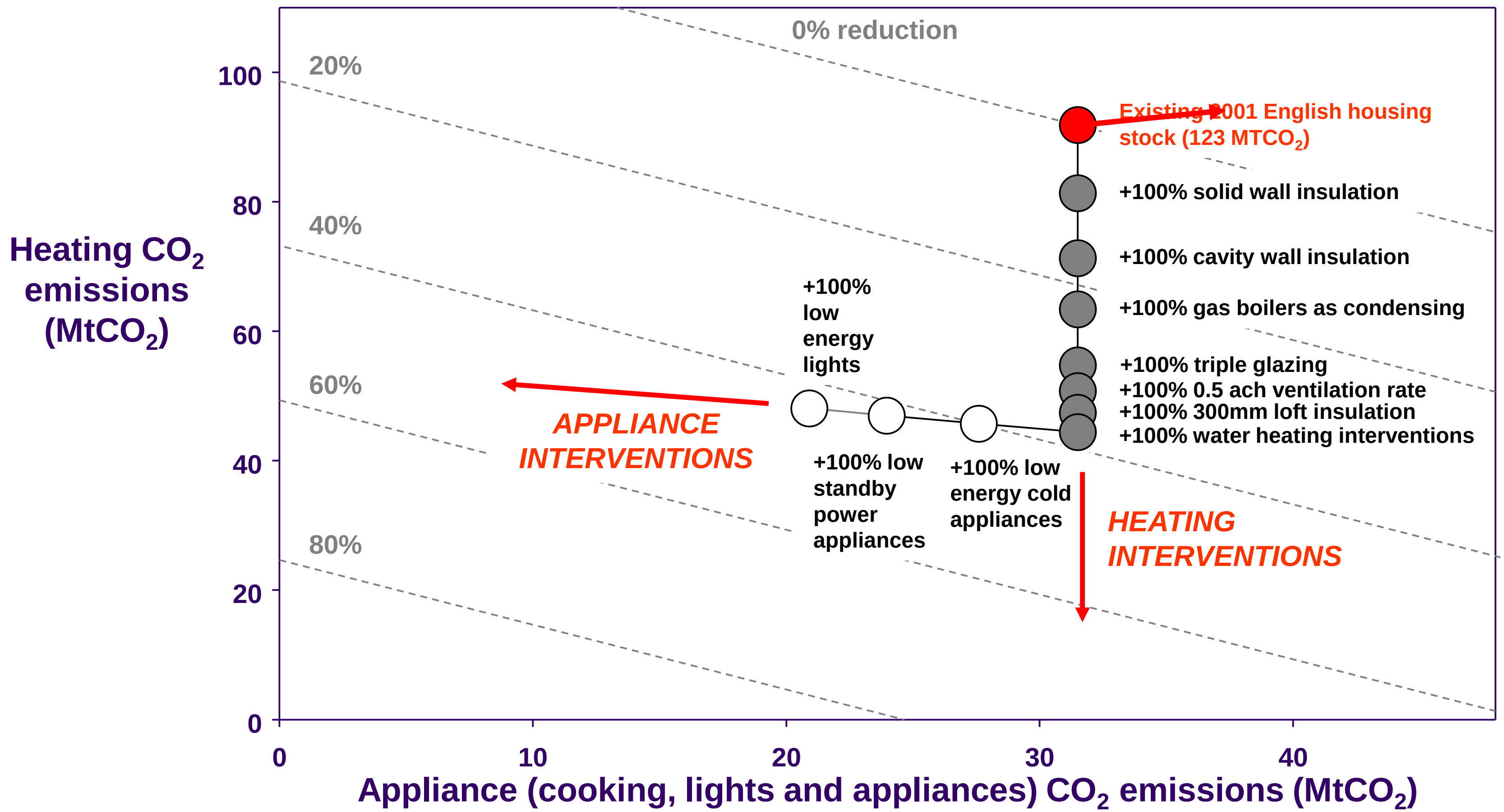

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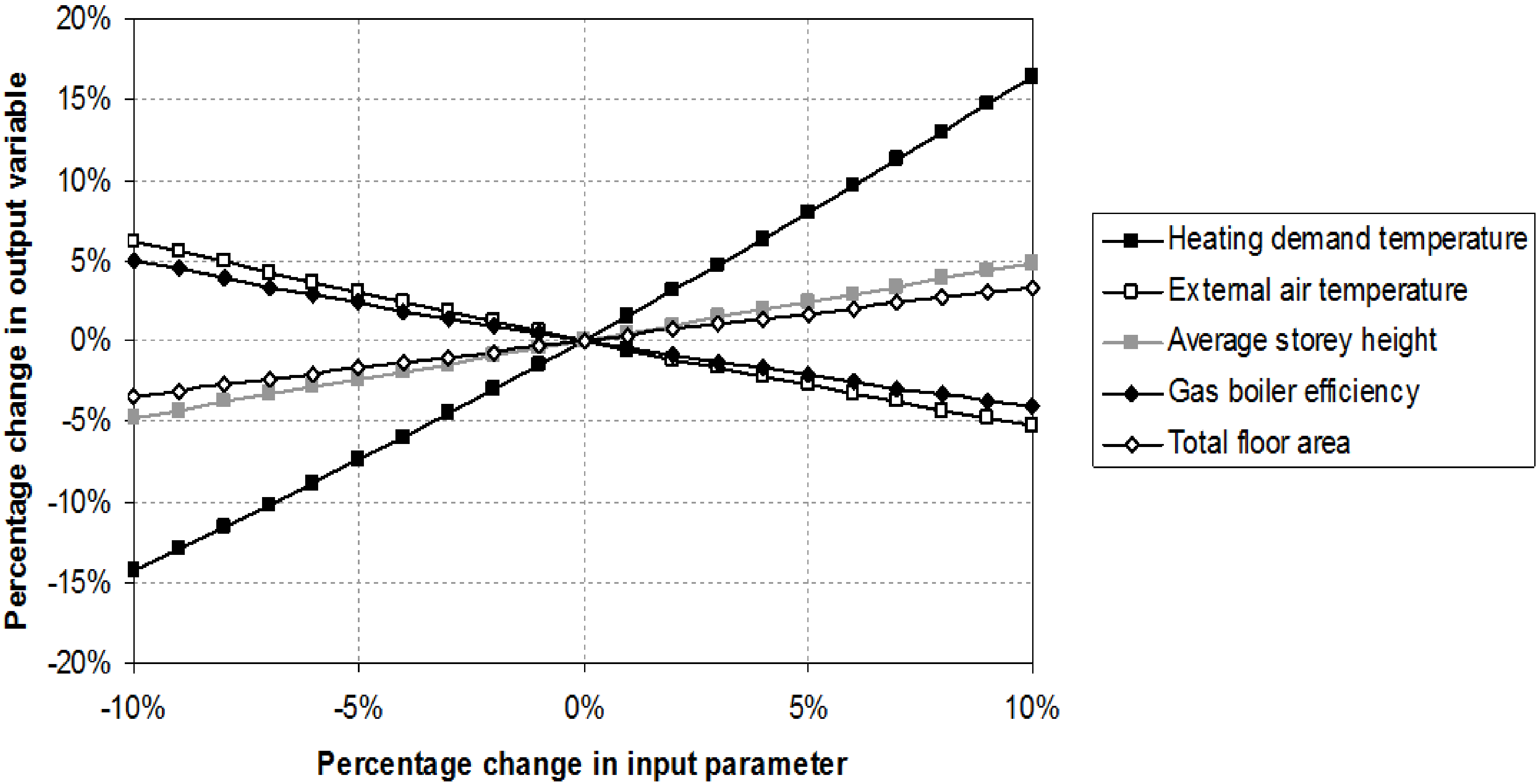
Sensitivities: percentage change in CO_2 emissions for stated change input values.



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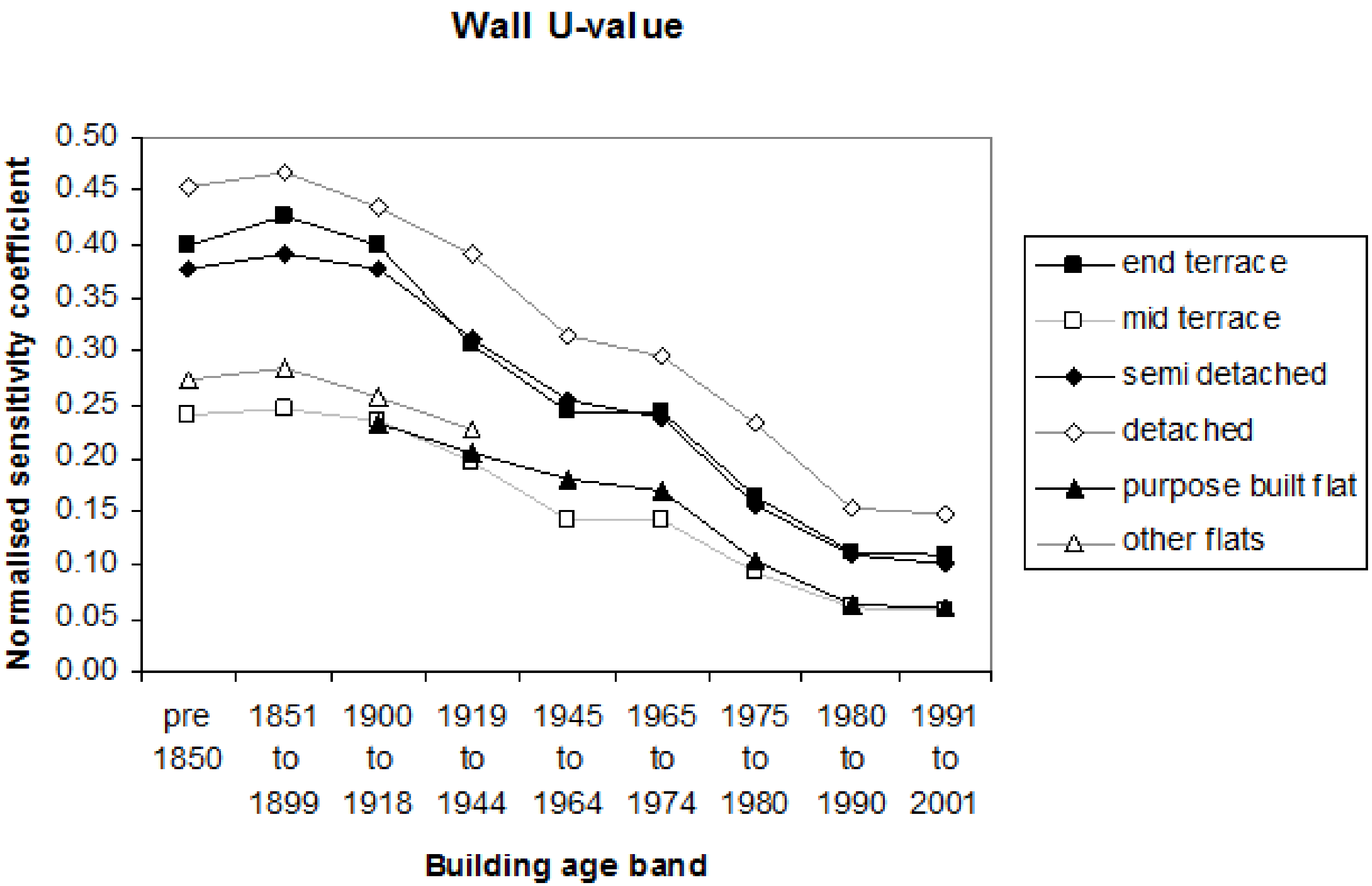
Percentage change in CO_2 emissions for 1% change in wall U-value



Simple, archetype stock model: advantages and limitations

Advantages

  - Fast, transparent, reproducible, desk top computer.

Limitations

- ***The methodology***
  - Cannot reproduce aggregated energy demand/CO_2 distributions.
  - Limited modelling of behaviour and its diversity.
  - Archetypes cannot capture the diverse physical forms of homes.
- ***The model***
  - Implausible and unrealistic heating demand profile imposed.
  - Growing evidence that energy demands are overestimated.
  - Cannot exhibit well-known take-back phenomena.

Stock modelling the sampling approach.

1. Measure the form and fabric of enough <u>actual</u> homes so capturing their physical variability.
2. Model an actual stock of homes by <u>sampling</u> from within this dataset of homes.
3. For example the 16,150 homes in the Cambridge Housing Model, which is derived from the English Housing Survey.
4. Impose heating profiles <u>stochastically</u> but account for any <u>correlations</u> between these profiles and occupant characteristics and built form.

Measuring heating patterns: the data set

- 4M Project - Measurement, Modelling, Mapping and Management: an Evidence-Based Methodology for Understanding and Shrinking the Urban Carbon Footprint
- 575 households, face-to-face household interviews.
- 249 produced useful temperature measurements.
- July 2009 to February 2010
- 93% centrally heated

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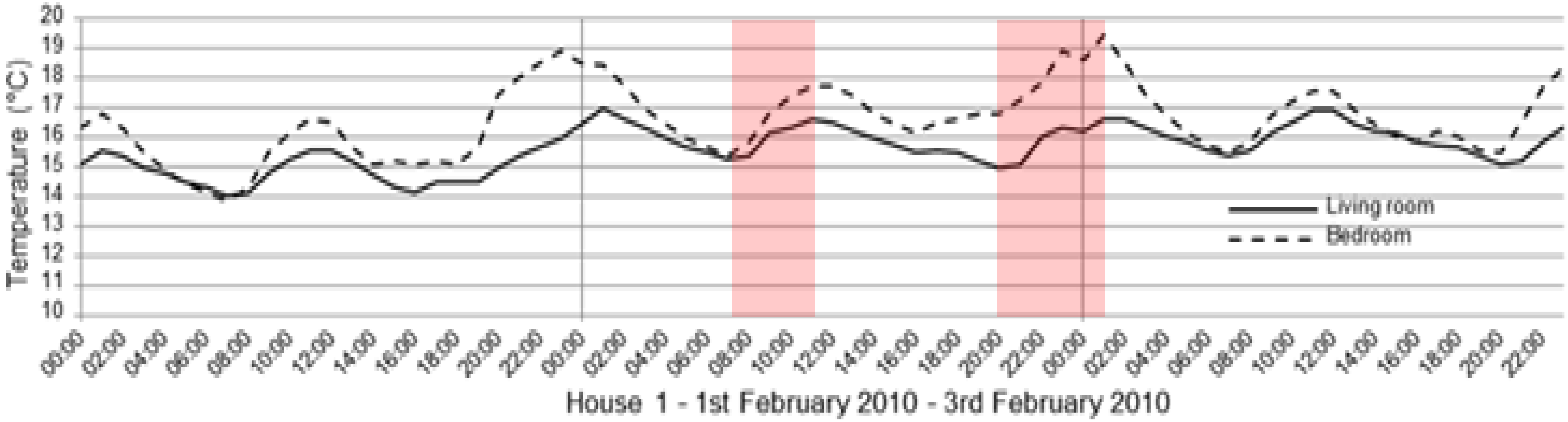
House 1: a typical, repeating, two-period heating pattern

- Highest temperature 19ºC, late evening.

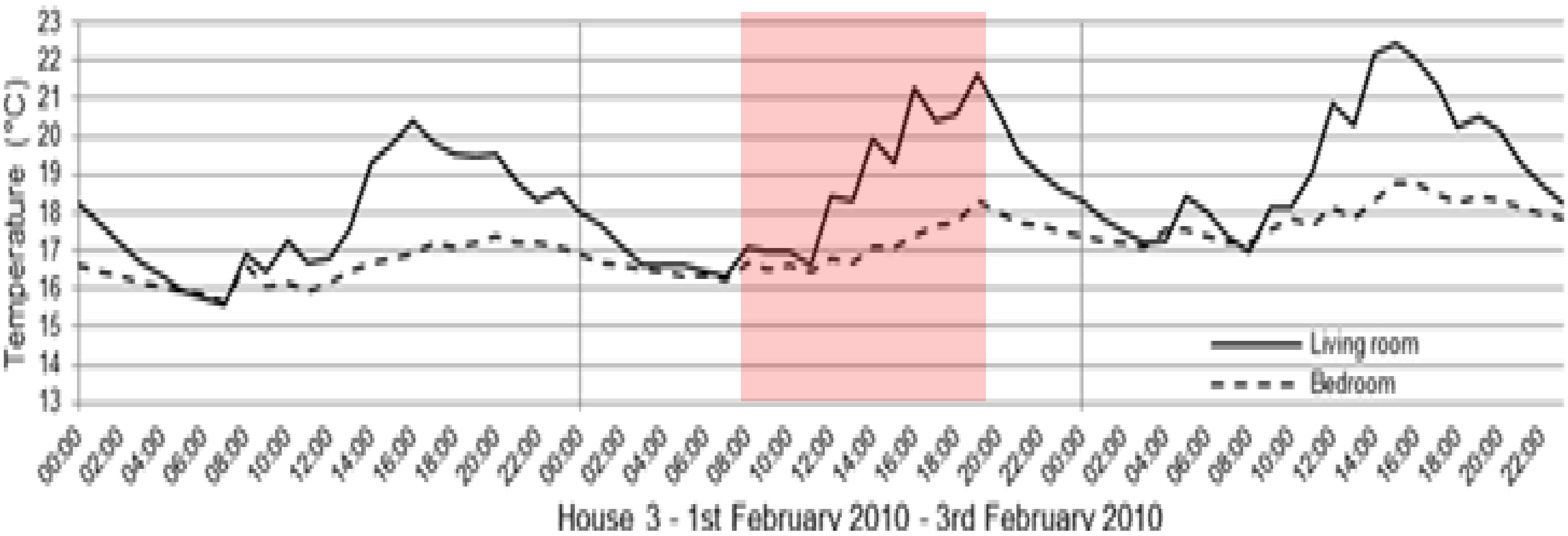


House 2: Not centrally heated – living room two period pattern, bedroom unheated

- Highest temperature 25^{o}C, late evening.

House 3: One-period pattern - bedroom more modestly heated (TRV is set low)?

- Highest temperature 22^{o}C, late evening.



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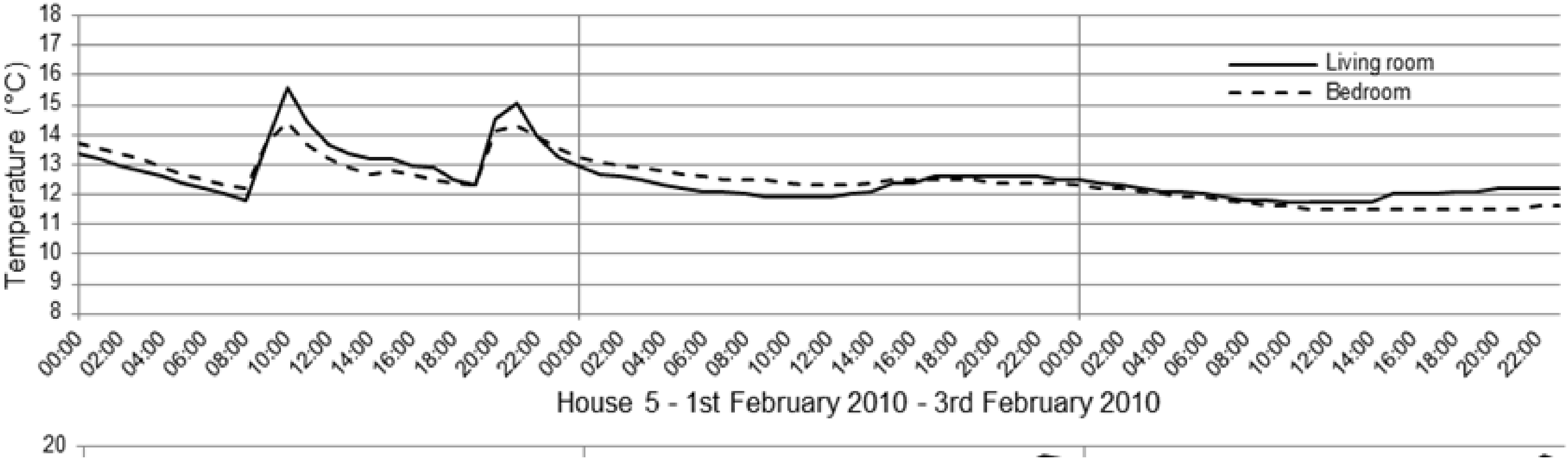
House 4: Two period pattern on the first day but no heating on days 2 and 3; (occupant intervention)?

- Highest temperature 16ºC.



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Observations on measured temperatures

- Heating patterns can vary greatly between houses.
- Temperatures achieved (or sought) vary greatly between houses.
- Heating patterns are hard to define from measured temperatures.
- A number of ‘metrics’ are needed to describe a heating patterns and temperatures.
- The patterns do not (nor could they) resemble the pattern assumed by BREDEM-based (SAP) models.

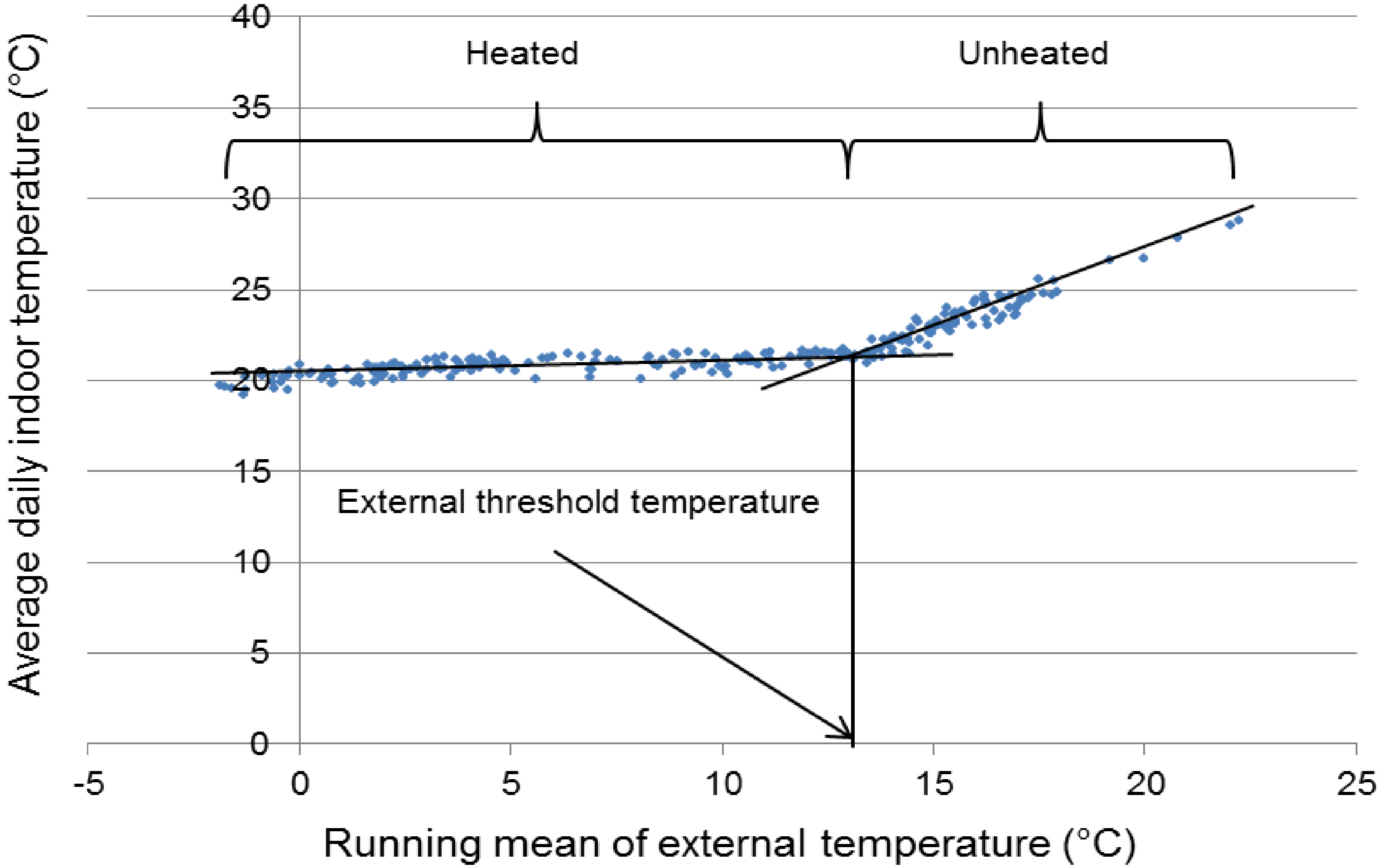
Describing the heating patterns

		Heating practice metric	Definition
Heating pattern	1)	External threshold temperature	The external air temperature a. below which the heating system is turned on[1] and b. above which it is turned off[2]
	2)	Number of heating periods per day	The number heating periods that are predominantly used[3]
	3)	Start and end times of heating periods	The median start and end times of each heating period for homes with a regular heating pattern[3]
	4)	Duration of heating per day	The average total duration of heating per day[3]
	5)	Number of under-heated days	The number of days during the winter analysis period which are heated for less than half of the average heating duration[3]

Describing the temperatures

		Heating practice metric	Definition
Resulting temperatures	6)	Mean winter temperature	The mean of all measured temperatures a. living room and b. bedroom[3].
	7)	ΔT_{room}	The average temperature difference between the living room and bedroom[3]
	8)	Mean achieved temperature	The average of the daily maximum temperatures measured in the living room[3]
	9)	Average temperature during heated periods	The average temperature calculated during each heating period a. living room and b. bedroom[3].

Finding the external threshold temperature



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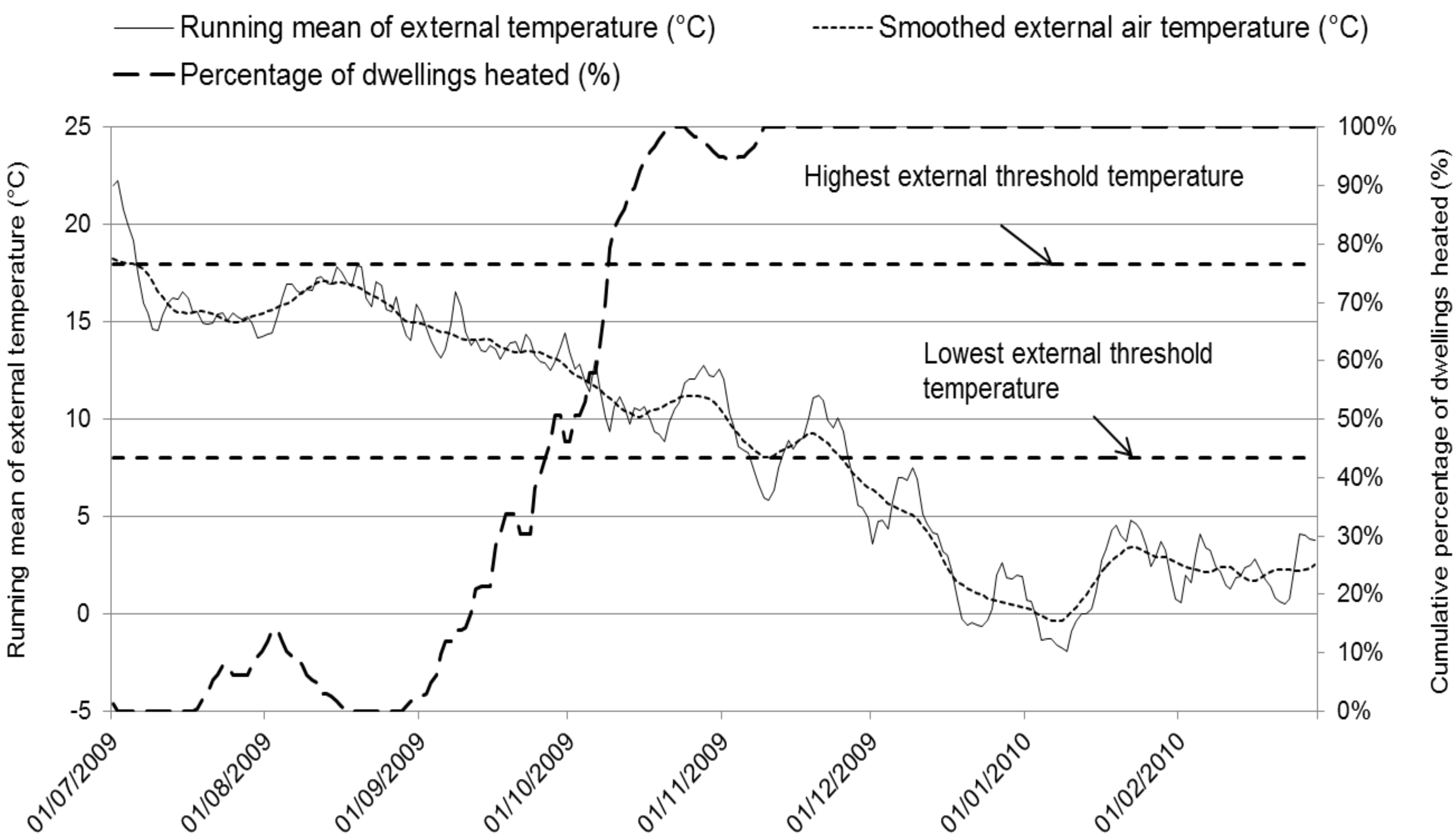
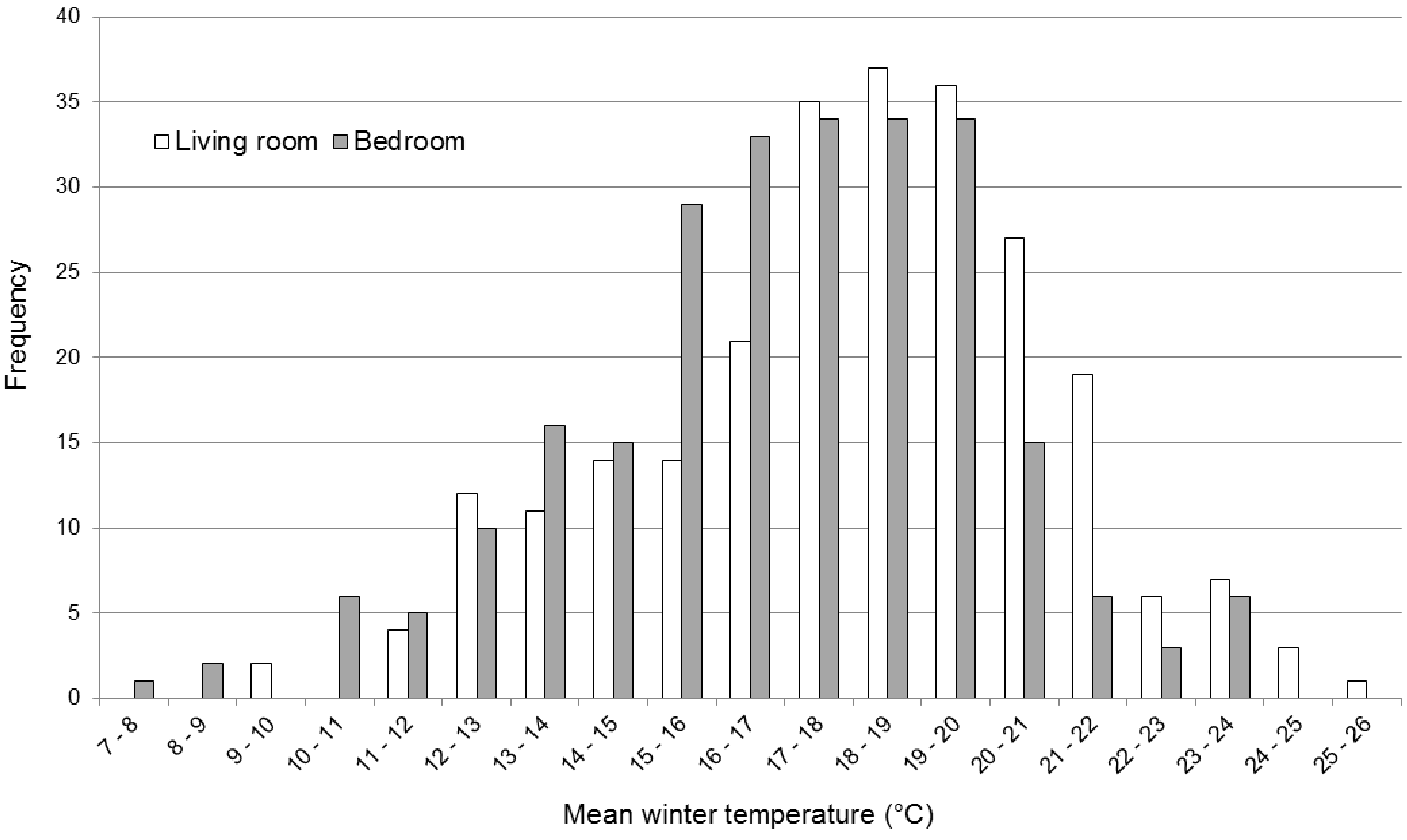
Distribution of threshold temperatures



Distribution of mean winter temperatures



Impact of dwelling type and construction on internal temperatures

Significant differences ($p<0.05$) exist between the mean winter temperatures in living rooms depending on house type and construction:

- Terraces (17.9°C) were significantly cooler than flats (20.0°C),
- Solid wall properties (18.0°C) were significantly cooler than those with insulated (filled) cavities (19.2°C).

Both results are consistent with the differences in heat loss between the dwelling types.

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Impact of occupants on internal temperatures

Significant differences exist between mean winter temperatures and heating patterns depending on ‘social’ characteristics.

- Single person households (17.7°C) are significantly cooler than homes with two occupants (19.0°C).
- The homes of over 60's (19.3°C/19.2°C) are significantly warmer than homes of under 20’s (16.4°C).
- Rented homes (19.1°C) are warmer than owner occupied homes (17.7°C).
- Households where the occupants are unable to work (20.6°C) are significantly warmer than those where the occupants are employed (17.9°C).

Age, number of occupants, tenure and work status significantly affect heating behaviour.

The differences are consistent with ‘life-style’ considerations..

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Stochastic occupancy modelling: prototype illustration

- Five occupancy patterns, but fixed temperature set-points (19^{o}C living and 18^{o}C bedroom).
- Dynamic model – Energy Plus.
- jEPlus for parallel running of simulations.
- 125 occupancy profiles simulated.

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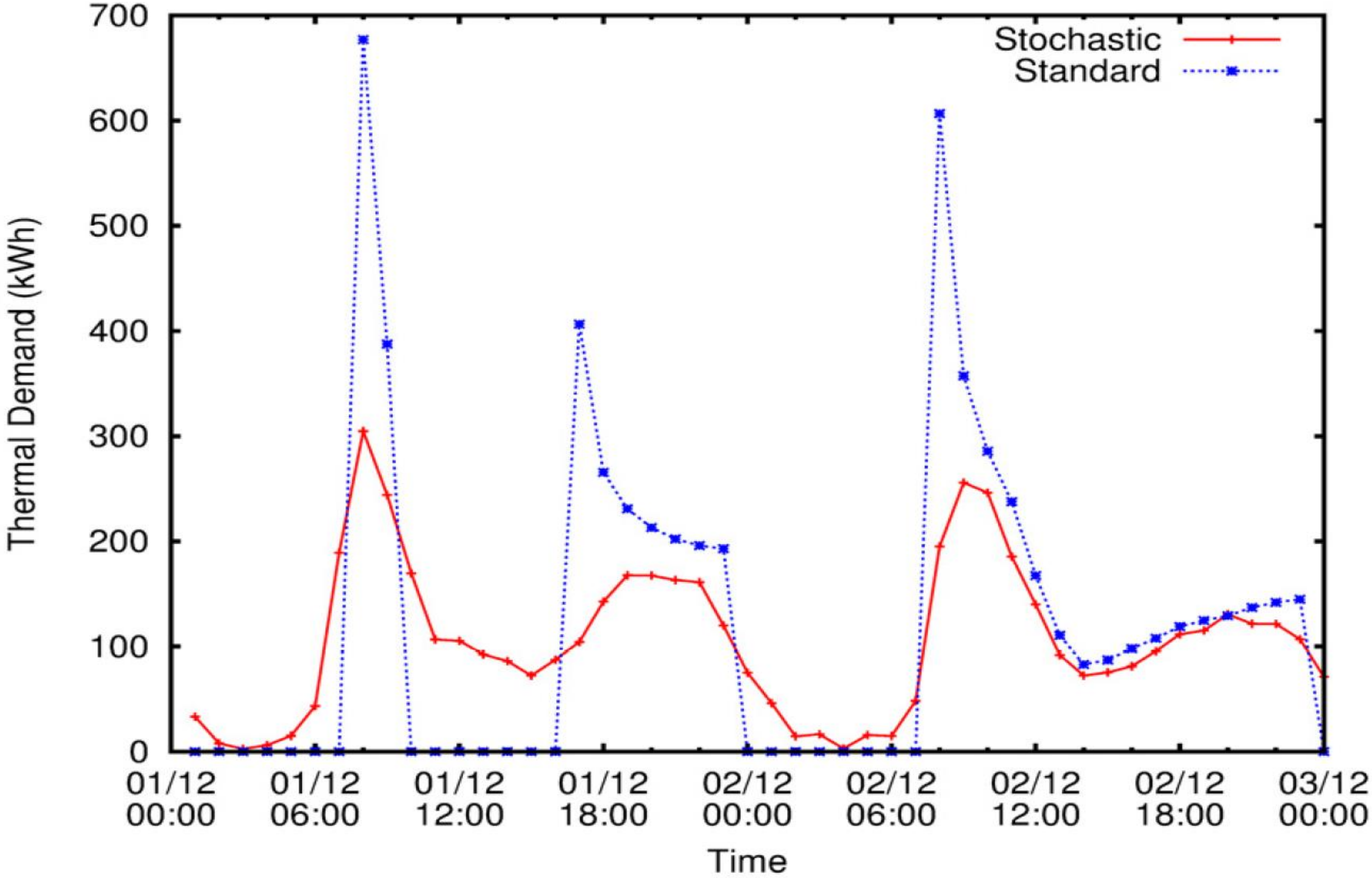
Stochastic modelling and case study

125 homes. Detached, semi-det., mid and end terrace. Built 2012-2015. Energy Rating B.

Aggregation of stochastically modelled heating patterns



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Capturing the diversity of heating in housing stocks.

- We cannot properly model heating in homes by imposing a pattern and internal temperature.
- The patterns and temperatures are a consequence of technical and social factors and their interaction:
  - the weather;
  - the house form, the insulation standards;
  - the characteristics of the occupants and their tenure;
  - the type of heating system and its controls.
- Dynamic models with stochastic, probabilistic occupancy modelling is needed.
- Large monitoring programmes are needed to provide the data needed to build such models.

- Thank you