UCL Energy Institute

Panel 5: **Understating the load patters in residential sector**
5-083-15

People use the services energy provides – but buildings and technologies determine how much is used

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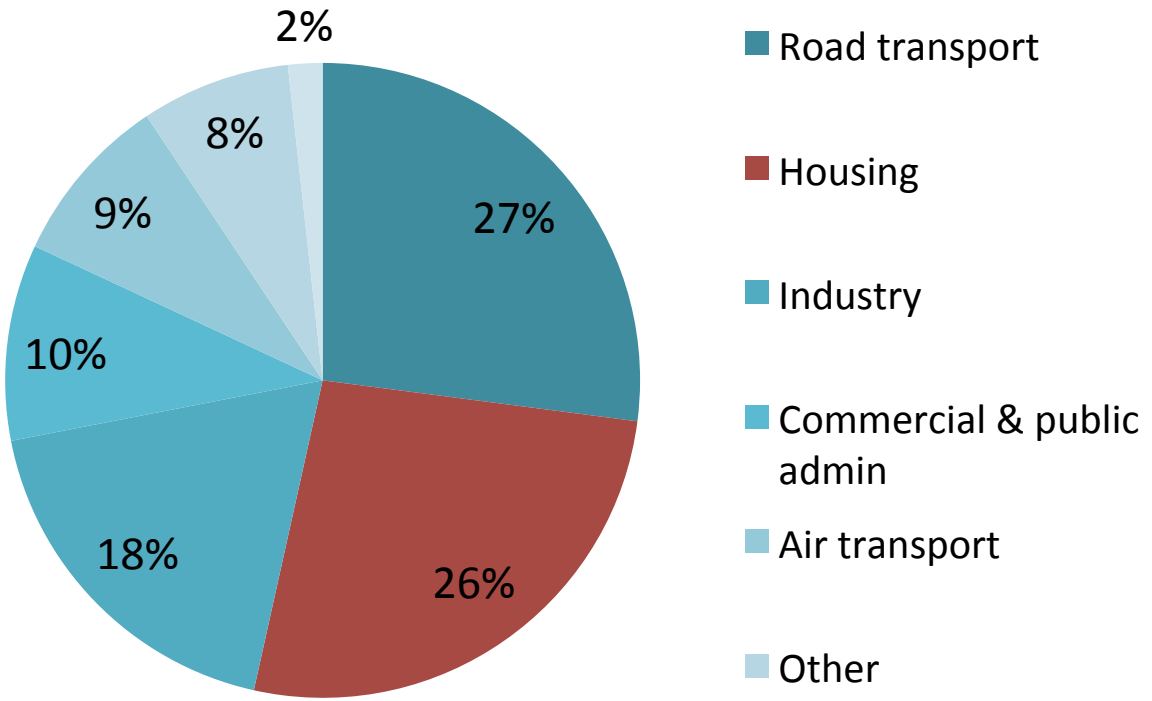
Why looking at homes?

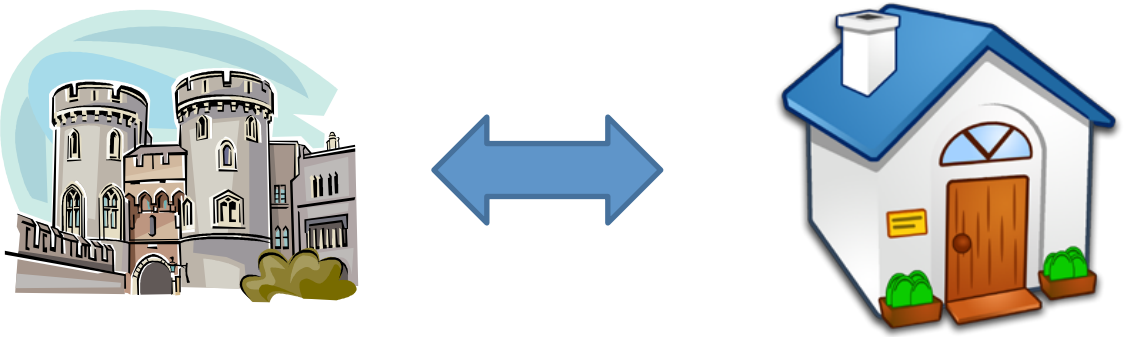
Final energy consumption by sector UK 2011



Aim:
Reduce emissions from homes by 29% by 2020 based on 2008 levels (DECC 2009).

"Buildings don't use energy: people do" (Janda, 2006)

- True: but the same people might use very different amounts of energy in different houses!



- What is the contribution of different types of predictors to domestic energy consumption?

Why do we need to know this?

- What kind of variables do we need to measure to understand energy consumption?
  - Often expensive / not feasible to measure all variables
  - Many variables change over time so ideally we could focus on the most stable ones
- Which interventions are most likely to result in reduction of energy consumption?

Previous findings – Building variables

- Building size and building type strongest predictors (Guerra Santin, et al., 2009)
- Location likewise important - > climatic differences (Steemers & Young Yun, 2009)
- Findings on building age unclear (Guerra Santin et al., 2009; Theodoridou et al., 2011)
- Double glazing and insulation levels of walls are associated with energy consumption but only moderately (Guerra Santin et al., 2009)

Previous findings – Socio-demographics

- Estimates vary significantly: 4.2% (Guerra Santin et al., 2009), 20% (Steemers & Young Yun, 2009, space heating), 18% (Sonderegger, 1978)
  - Only Guerra Santin controlled for building variables
- Generally: household size and income most important predictors (Brandon & Lewis, 1999; Druckman & Jackson, 2008)
- Role of age unclear (Gatersleben, Steg, & Vlek, 2002 vs. Abrahamse & Steg, 2009 vs. Liao & Chang, 2002)
- Tenure (Palmer & Cooper, 2012) – but likely confounded with building variables

Previous findings – Heating behaviour

- In building stock models, heating demand temperature most important input variable, followed by heating pattern (Firth, Lomas, & Wright, 2010).
- Link between indoor temperature and space heating demand (Haas, Auer, & Biermayr, 1998) and total energy consumption (Palmborg, 1986)
- Link between heating set point and space heating demand (Steemers & Young Yun, 2009)
- Link of proportion of heated rooms (Steemers & Young, 2009) and bed rooms (Guerra Santin et al., 2009) to energy consumption

Previous findings – Psychological constructs

- No relationship between domestic energy requirements and values / problem perception of climate change (Vringer & Blok, 2007)
- Psychological variables such as attitudes and perceived behavioural control not related to energy consumption but only to success in an intervention program (Abrahamse & Steg, 2009; Brandon & Lewis, 1999)
- Self-reported habit strength was significantly related to self-reported energy consuming behaviours and to actual energy consumption (Huebner et al., 2013)

Positioning our work

Many of the previous studies….

- did not include all variables classes
  - Here: building, socio-demographics, heating-behaviour, and "psychological" variables
- Did not control for multicollinearity between predictors - problematic because it leads to instable regression coefficients
  - Here: Variance inflation factors inspected and variables selected to avoid multicollinearity
- Did not show incremental explanatory power
  - Here: show explanatory power of individual and combined regression models

Methods - Data

- Two nationally representative surveys:
  - Energy-Follow-Up Survey (EFUS)
    - Heating behaviour
    - Attitudes towards climate change
    - Self-reported behaviours
    - Meter readings to get estimate of annual energy consumption
  - English Housing Survey (EHS)
    - Building variables
    - Socio-demographics
- N = 991 households (for 'psychological' variables N = 924)

Methods - Analysis

- Linear regression to explain annual (log-transformed) domestic energy consumption
- Calculation of variance inflation factors: if > 3.3, then exclusion of critical variables
- Four individual models, then combination of models and test for significance differences

Building variables

Variable (abbreviation)	Categories (N)
Floor area (FloorArea)	n/a (continuous: M = 91.12 m^2, SD = 43.07)
Dwelling type (DwType)	Converted & purpose built flat (151), detached (234), end terrace (119), mid-terrace (119), semi-detached (305)
Number of storeys (NoStorey)	n/a (continuous: M = 2.11; SD = 0.85)
Government Office Region (GOR)	East (108), East Midlands (68), London (106), North East (73), North-West (176), South East (134), South-West (96), West Midlands (97), Yorkshire and the Humber (133)
Dwelling age (DwAge)	pre 1919 (142), 1919-44 (171), 1945-64 (229), 1965-80 (233), 1981-90 (77), post 1990 (139),
Wall type (WallType)	9-inch solid wall (139), cavity uninsulated (302), cavity with insulation(489), other (63)
Double glazing (DblgGlaz)	entire house (786), more than half (117), less than half (38), no double glazing (35)
Loft insulation (LoftIns)	150mm or more (457), 100 up to 150mm (257), none – up to 100 mm (172), not applicable - no roof directly above (105)
Attic (Attic)	Yes (106), no (885)
Conservatory (Conservatory)	Yes (195), no (796)
Fuel type (Fuel)	electrical system (46), gas system (945)
SAP rating (SAP)	C (134), D (552), E(256), F&G (49)

Socio-demographic variables

Variable (abbreviation)	Categories (N)
Household size (HHSize)	n/a (continous: M = 2.37, SD = 1.24)
Age of youngest dependent children (DepChild)	No dependent children (680), 0-4 years (130), 5-10 years (88), 11-15 (63), older than 16 (30)
AHC (After-Housing-Costs) equivalised income quintiles (Income)	1st quintile – lowest (145), 2nd quintile (218), 3rd quintile (209), 4th quintile (209), 5th quintile- highest (210)
Tenure (Tenure)	Local authority (117), owner occupied (633), private rented (101), Registered Social Landlord RSL (140)
Sex of Household Reference Person (SexHRP)	Female (391), male (600)
Age of HRP (AgeHRP)	16 - 29 yrs (49), 30 - 44 (238), 45 - 64 (404), 65 or over (300)
Employment status of household (EmployHH)	1 or more work full time (482), 1 or more work part time (86), none working and none retired (97), none working, one or more retired (326)
Someone in household sick or disabled? (sick/disabled)	No (647), yes (344)
Someone in household over 75 years?	No (868), yes (123)
Length residency (LengthRes)	2 yrs or less (168), 3-4yrs (116), 5-9years (195), 10-19 (216), 20-29 (134), 30+years (162)

Heating behaviour

Variable (abbreviation)	Categories (N)
Timer used (Timer)	No (391), Yes (600)
Proportion of rooms heated by supplementary heating (SupplHeating)	More than 20% (446), 20%-50% (50), none (495)
Proportion of rooms not heated (PropNotHeated)	None (371), up to 10% (115), 10-20% (225), 20-50% (209), Over 50% (41)
Length heating season (HeatingSeason)	not applicable (45), 1-3months (65), 4months (141), 5months (246), 6 months (268), 7 months (141), 8months (52), 9-12months (33)
Heating duration hrs/day (HeatingDuration)	na (264), <4hrs (486), 4-10hrs (97), 11-16hrs (97), >17hrs (47)

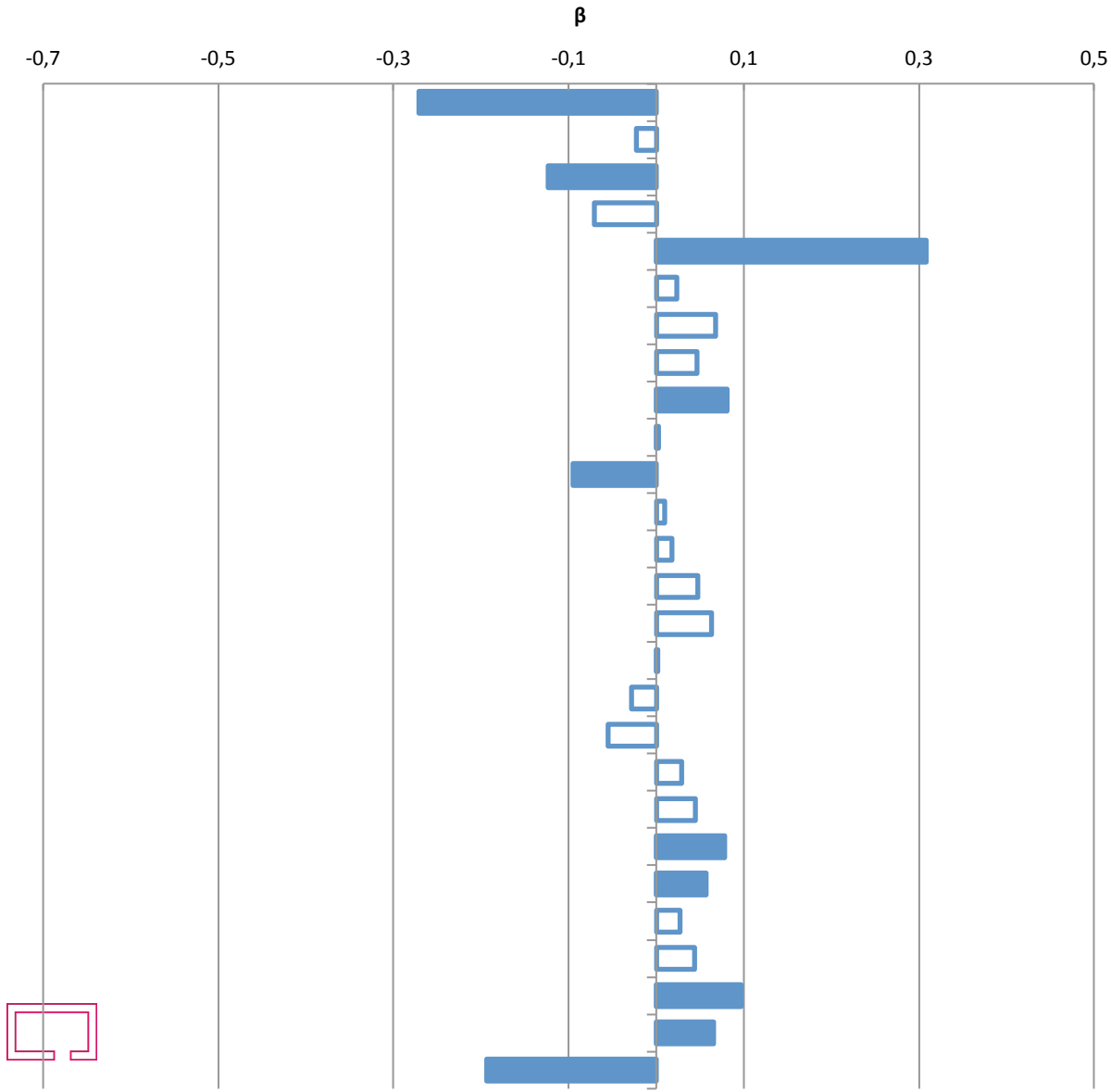
'Psychological variables'

	Variable (abbreviation)	M (SD)
Answer scale	Do you agree that….	
1 = Agree strongly **2 = Tend to agree** **3 = Neither agree nor disagree** **4 = Tend to disagree** **5 = Disagree strongly**	The Government is taking sufficient action to tackle climate change? (Government)	3.19 (1.03)
	It would embarrass me if my friends thought my lifestyle was purposefully environmentally friendly? (Embarrass)	3.06 (1.07)
	Being green is an alternative lifestyle, it's not for the majority? (BeingGreen)	3.05 (1.22)
	I find it hard to change my habits to be more environmentally-friendly? (Habit)	3.32 (1.20)
	It's not worth me doing things to help the environment if others don't do the same? (NotWorth)	3.64 (1.27)
Answer scale	How often, if at all, do you personally...	
1 = Always **2 = very often** **3 = Quite often** **4 = occasionally** **5 = never**	Switch off lights when you are not in the room? (LightsOff)	1.64 (0.98)
	Boil the kettle with more water than you are going to use? (BoilKettle)	3.73 (1.31)
	Leave your TV or PC on standby for long periods of time? (TVStandby)	357 (1.62)
	Wash clothes at 30 degrees or lower? (Wash30)	3.35 (1.59)

Psychological variables II

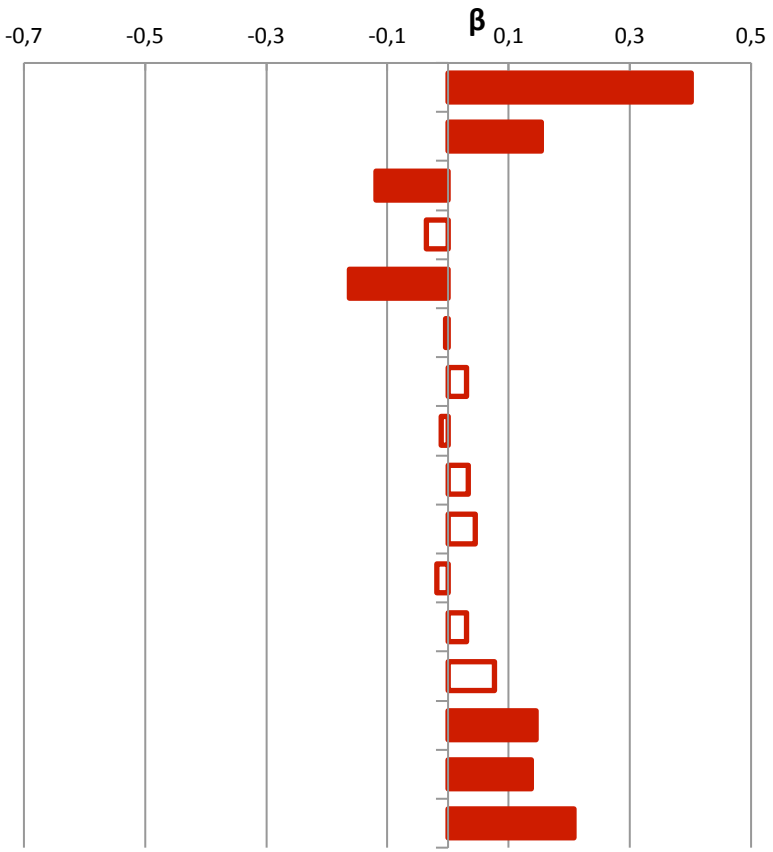
- Climate change is caused by energy use and I'm beginning to think that I **should do something** (N = 102)
- Climate change is caused by energy use and I'm **doing a few small things** to help reduce my energy use and emissions (N = 407).
- Climate change is caused by energy use and I'm **doing lots of things** to help reduce my energy use and emissions (N = 49).
- Climate change is caused by energy use and I'm **doing quite a number** of things to help reduce my energy use and emissions (N = 220).
- Don't know (50). – **don't know**
- I **don't believe** there are climate change problems caused by energy use and I'm **not willing or able to change my behaviour** (N = 54).
- Whether there are climate change issues or not, I **am not willing or able to change** my behaviour with regards to energy use (N = 68).

Building variables explain 40% of variability



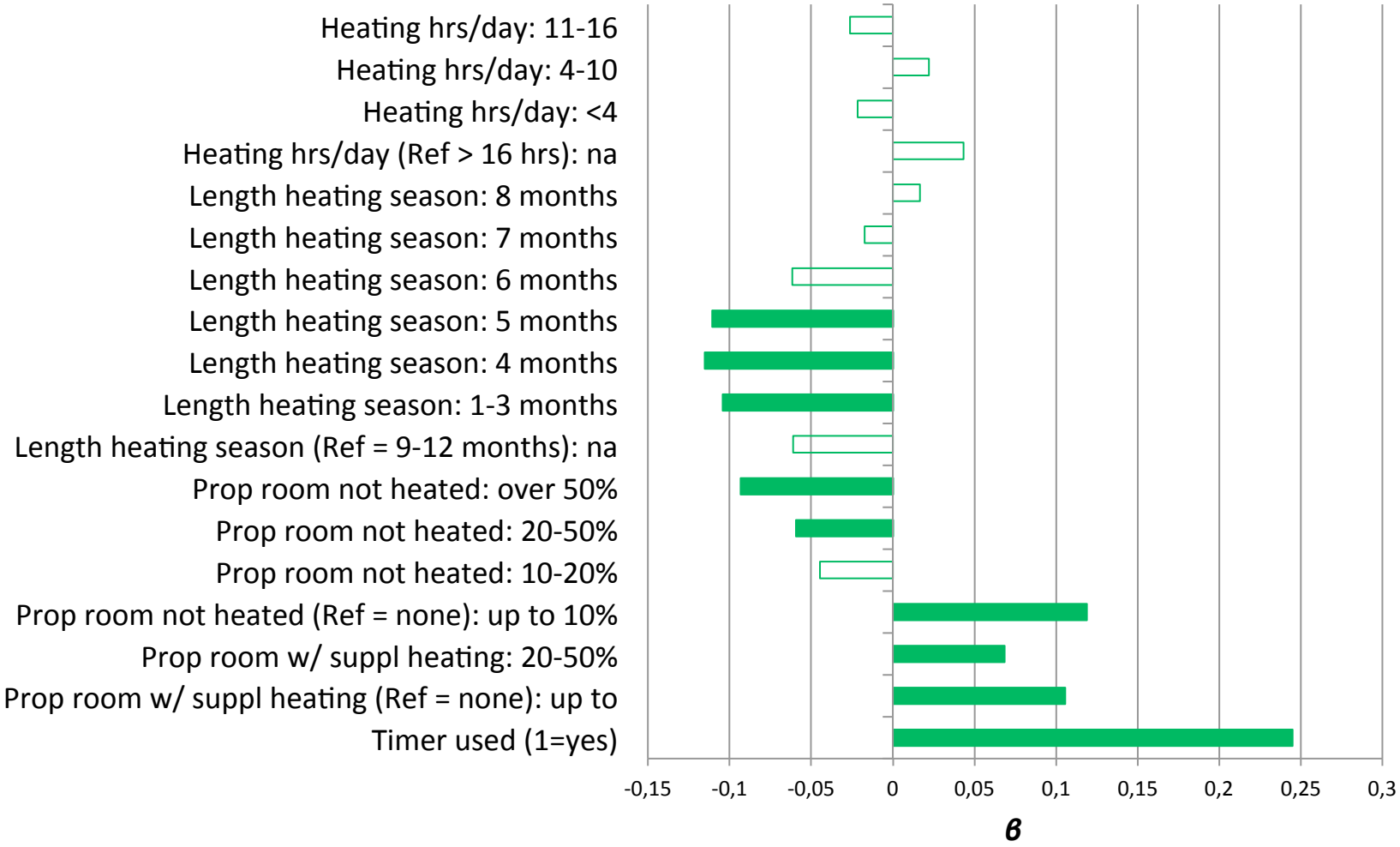
Dwtype (Ref= Detached): Flats***
Dwtype: EndTerrace
Dwtype: MidTerrace**
Dwtype: Semi
Floor area***
GOR (Ref=East): Midlands
GOR: London
GOR: North East
GOR:North-West*
GOR: South East
GOR: South West**
GOR: WestMidlands
GOR: Yorkshire&Humber
Dwage (Ref = pre1919): 1919-44
Dwage: 1945-64
Dwage: 1965-80
Dwage: 1981-90
Dwage: post1990
Wall (Ref = Cav. ins): Solid
Wall: Cavity uninsulated
Wall: Other**
Double glazing (Ref=all): More than half*
Double glazing: Less than half
Double glazing: None
Attic (1=yes)***
Conservatory (1=yes)*
Fuel type (1=electric)***

Sociodemographics explain 25.4% of variability

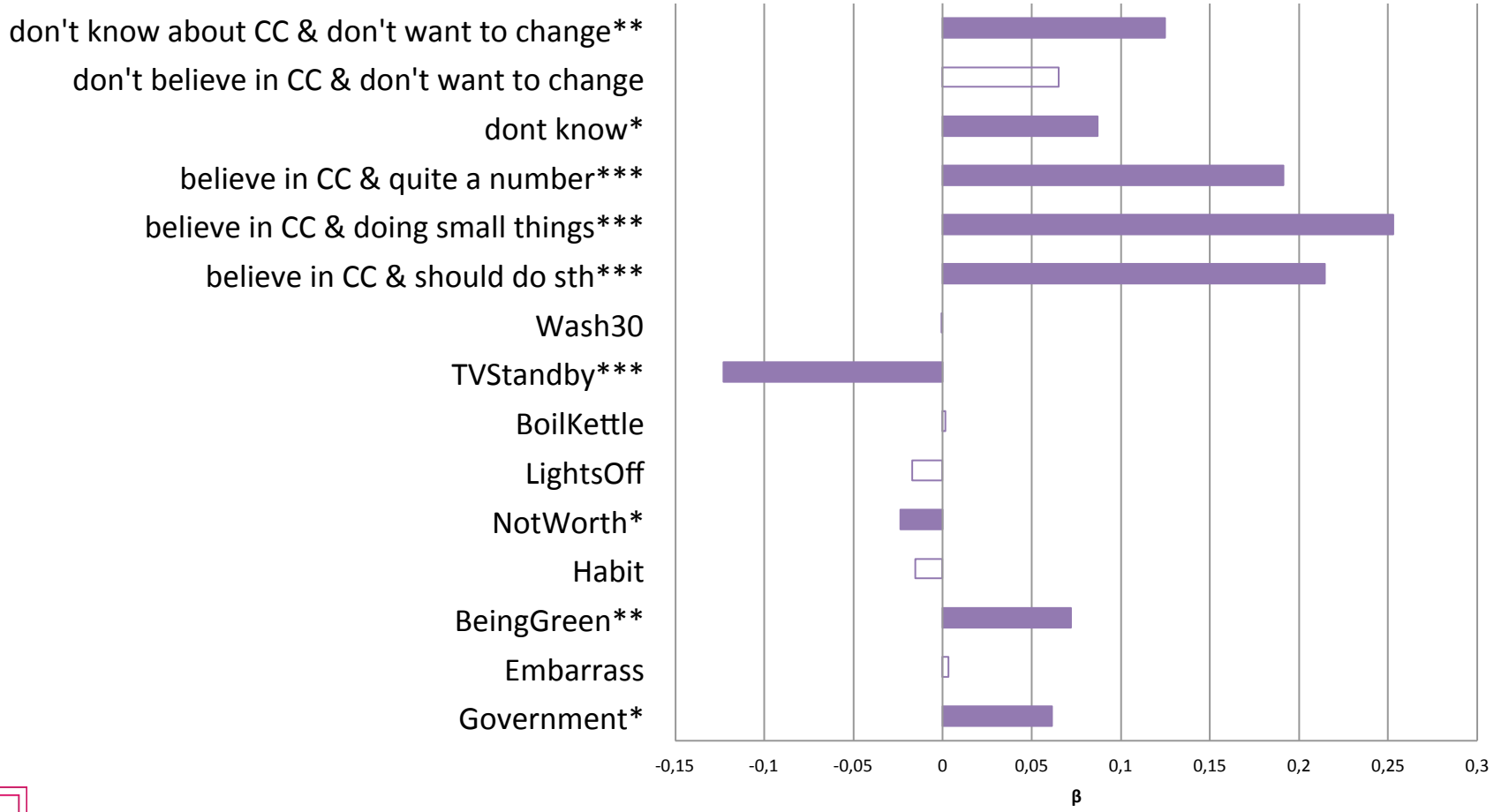


Household size***
Income**
Tenure (Ref=Owner occ): Local authority***
Tenure: private landlord
Tenure: RSL***
Gender HRP (1=female)
Employment (Ref=min 1 full time): at least 1 part time
Employment: none working, none retired
Employment: none working, at least 1 retired
Sick or disabled person (1=yes)
Person over 75 yrs (1=yes)
Length residency (Ref ≤ 2 yrs): 3-4yrs
Length residency: 5-9 yrs
Length residency: 10-19 yrs***
Length residency: 20-29 yrs***
Length residency: 30+ yrs***

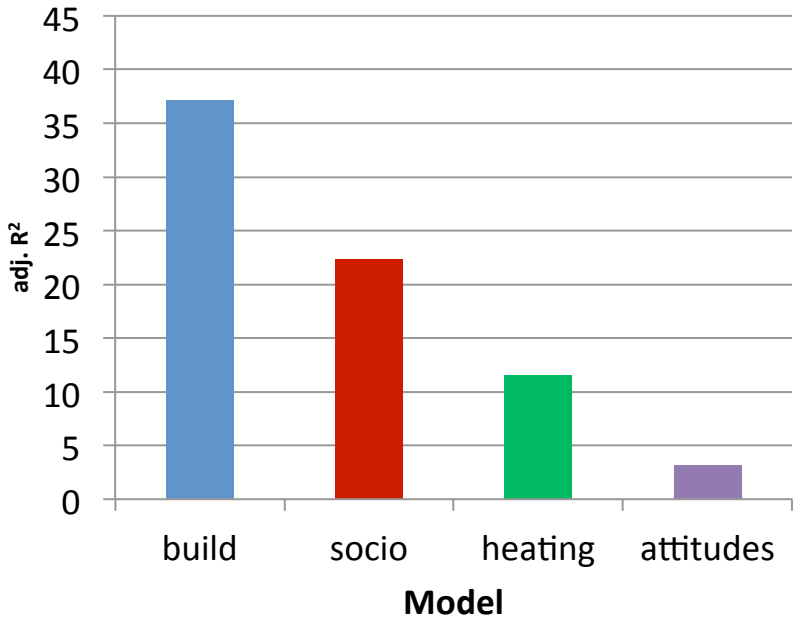
Heating behaviour explains 11% of variability

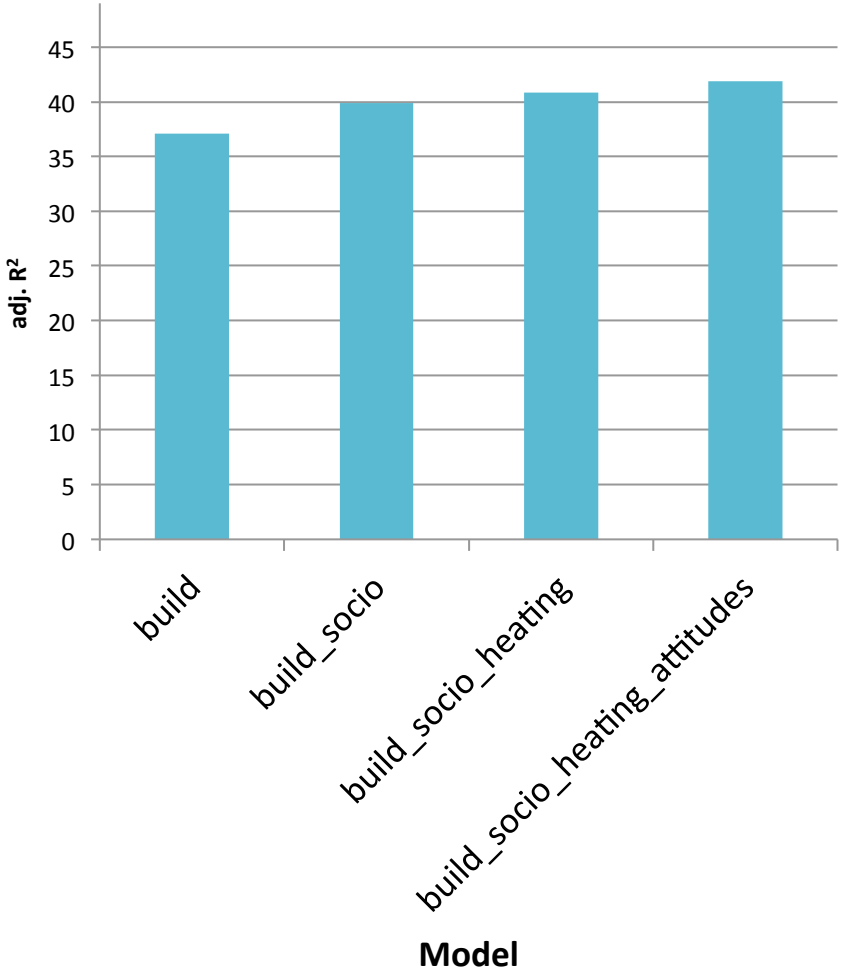


Psych. variables explain 4.2% of variability

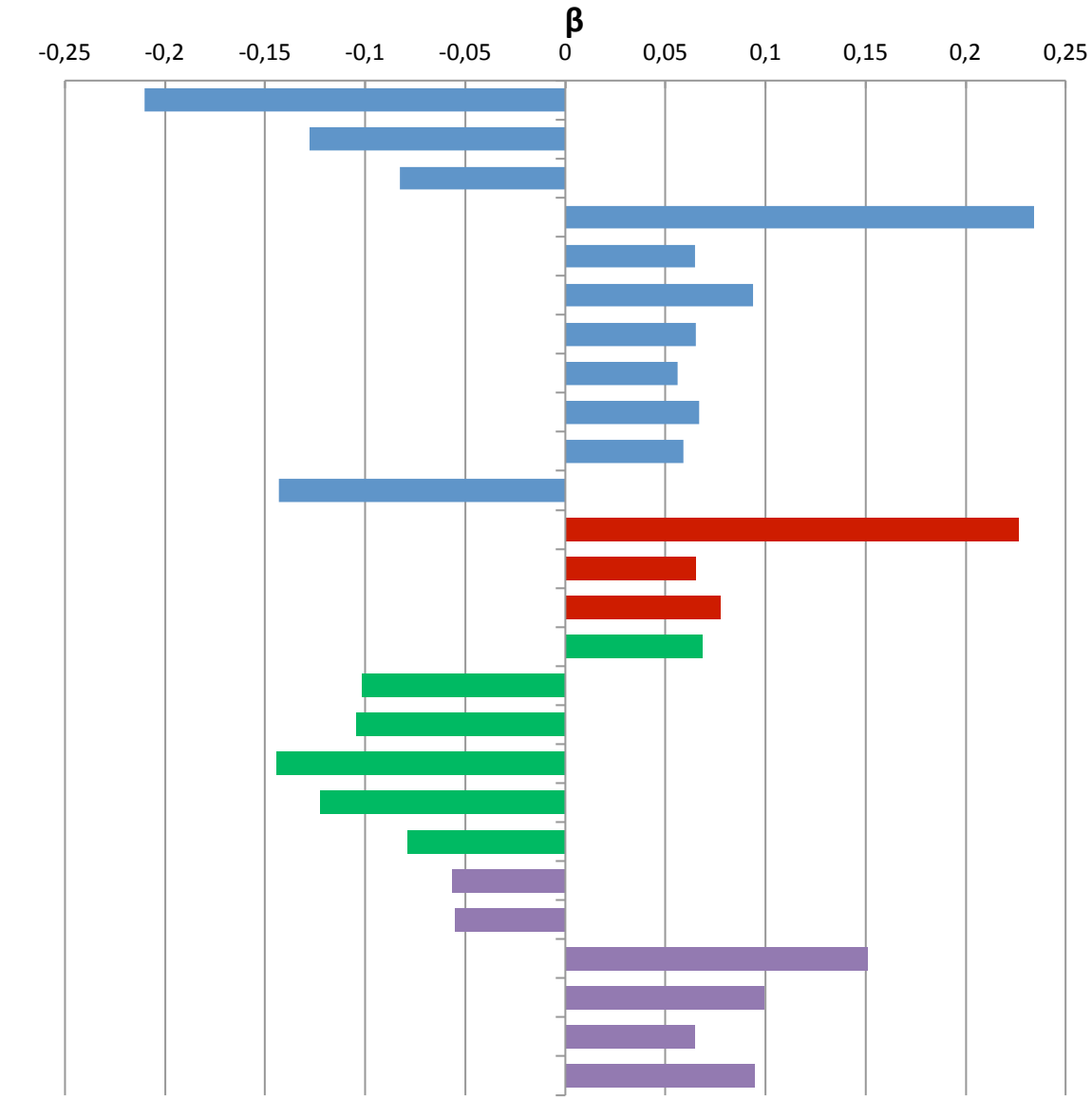


Model comparison (N = 924)





Building variables explain most!
All other models increase explanatory power significantly!



Dwtype: Flats***
Dwtype: MidTerrace**
Dwtype: Semi**
Floor area***
GOR: North East*
GOR:North-West**
Wall: Other**
Double glazing: more than half**
Attic (1=yes)**
Conservatory (1=yes)**
Fuel type (1=electric)***
Household size***
Length residency: 10-19 yrs*
Length residency: 30+ yrs*
Timer used (1=yes)*
Length heating season: 1-3 months***
Length heating season: 4 months*
Length heating season: 5 months**
Heating hrs/day: <4*
Heating hrs/day: 11-16*
NotWorth**
TVStandby*
believe in CC & should do sth***
believe in CC & doing small things**
believe in CC & quite a number*
dont know*

Summary

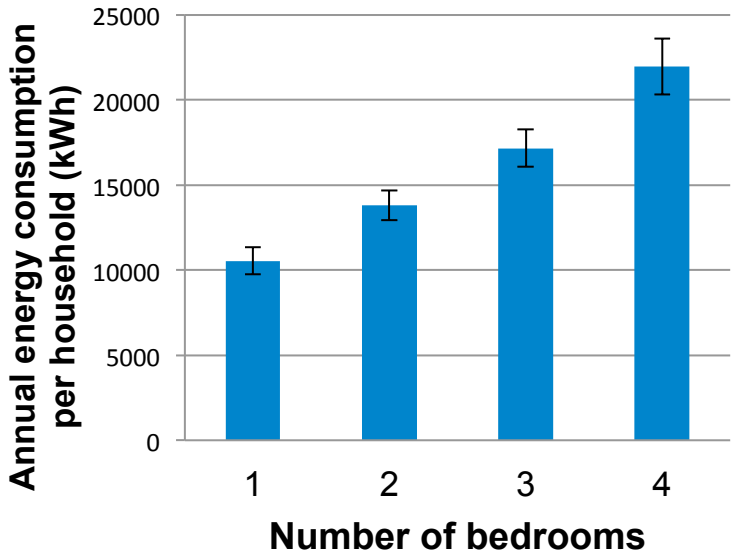
- Building variables explain most of domestic energy consumption
  - 'best' variables to measure!?
- Heating behaviours and psychological variables add about 6% to explanatory power
- **More than half of variability remains unexplained!**

Methodological issues

- Need statistically sound ways of addressing multicollinearity
  - Currently: using Lasso regression for variable selection
- Are we measuring the right variables / in the right way?
  - Concerns around self-report (Gauthier & Shipworth)
  - Internal temperatures potentially crucial predictor
  - Practices?

Implications for interventions

- Retrofit measures have some effect
- Can we encourage shorter heating periods?
- Can we encourage living in smaller homes?



Thanks!

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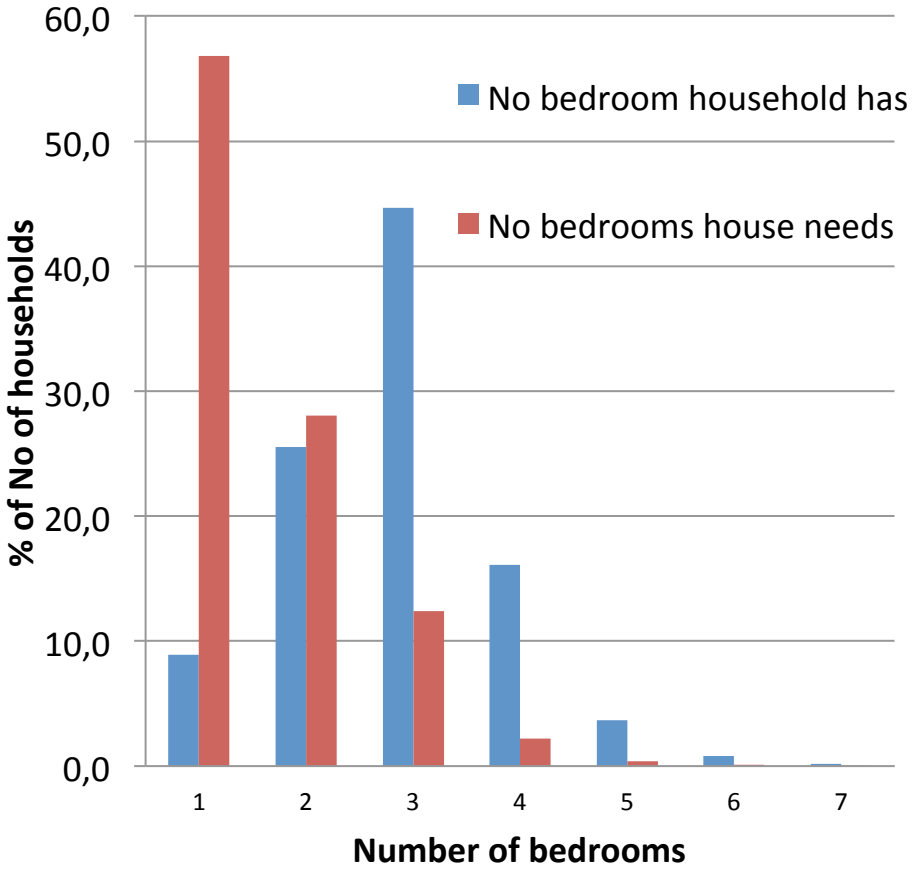
Downsizing homes to downsize energy consumption?

- Significant amount of under-occupying in the UK
  - 8 million households have two or more bedrooms than needed according to the bedroom standard
  - Further 7.7. million have one bedroom more
- No equivalent in terms of overcrowding : 3%

ONS, 2014

But: no alternative housing available



Can we convert large properties into smaller properties?

Mitigate housing crisis & reduce energy consumption

References

- Abrahamse, W. & Steg, L. (2009). How do socio-demographic and psychological factors relate to households' direct and indirect energy use and savings? Journal of Economic Psychology 30, 711–720.
- Druckman, A., & Jackson, T. (2008). Household energy consumption in the UK: a highly geographically and socio-economically disaggregated model. Energy Policy, 36(8), 3177–3192.
- Firth, S.K., Lomas, K.J., & Wright, A.J. (2010). Targeting household energy-efficiency measures using sensitivity analysis, Building Research & Information 38, 25 - 41.
- Gatersleben, B., Steg, L., & Vlek, C. (2002). Measurement and determinants of environmentally significant consumer behavior, Environment and Behavior 34 (3), 335–362.
- Guerra Santin, O., Itard, L. & Visscher, H. (2009). The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock. Energy and Buildings 41, 1223-1232.
- Haas, R., Auer, H., & Biermayr, P. (1998). The impact of consumer behavior on residential energy demand for space heating. Energy and Buildings, 27(2), 195-205.
- Huebner, G.M., Cooper, J. & Jones, K. (2013a). Domestic energy consumption - What role do comfort, habit, and knowledge about the heating system play?. Energy and Buildings, 66, 626-636.
- Janda, K.B. (2011) Buildings don't use energy: people do. Architectural Science Review, 54(1), 15-22J.
- ONS (2014). Overcrowding and Under-occupation in England and Wales. http://www.ons.gov.uk/ons/dcp171776_360082.pdf. Accessed 12.03.2015.
- Palmer,J. & Cooper, I. (2012). United Kingdom Energy Housing Factfile. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/201167/uk_housing_fact_file_2012.pdf. Accessed August 29 2014.
- Sonderegger, R.C. (1978). Movers and stayers: the resident's contribution to variation across houses in energy consumption for space heating, Energy and Building, 313–324.
- Steemers, K. & Young Yun, G. (2009). Household energy consumption: a study of the role of occupants. BRI, 37(5-6), 625-637.
- Theodoridou, I., Papadopoulos, A.M., & Hegger, M. (2011). Statistical analysis of the Greek residential building stock, Energy and Buildings, Volume 43, Issue 9, September 2011, Pages 2422-2428
- Vringer, K. & Blok, T. (2007). Household energy requirement and value patterns, Energy Policy 35, 553–566.

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