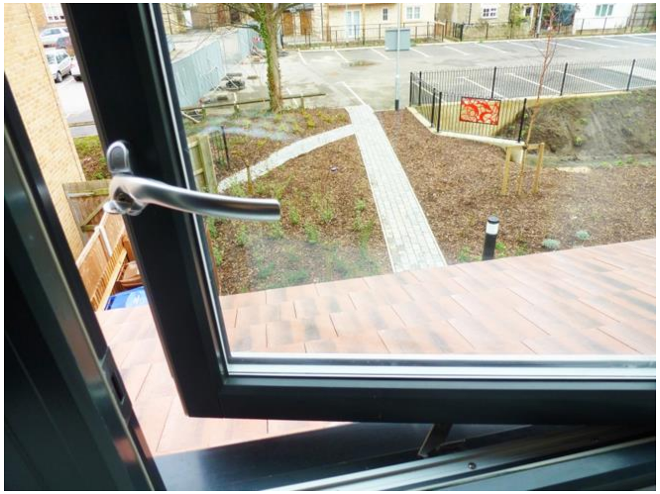
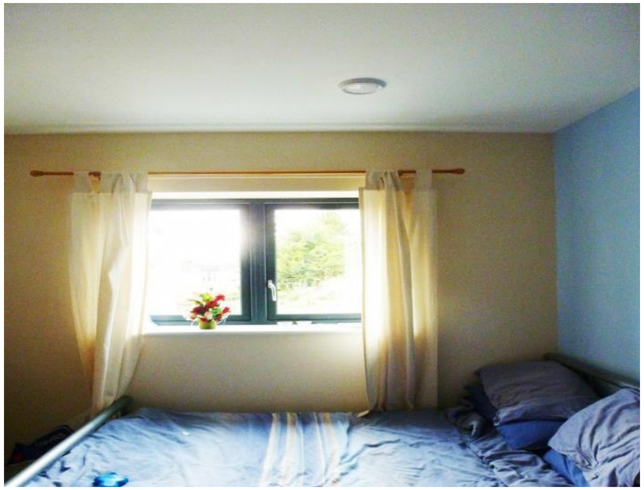
Meta-study of the energy performance gap in UK low energy housing

ECEEE 2019 Summer Study

3 June - 8 June 2019, Hyeres, France





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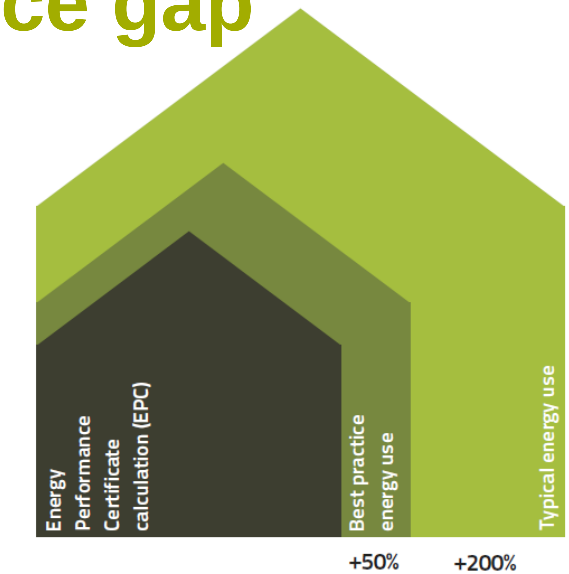
Outline

- **Context** and overview of the study
- **Findings**
  - Measured energy use
  - Energy performance gap
  - Occupancy related factors
- **Implications** for policy
- **Conclusions**

Gap between modelled and in-use energy performance: Energy performance gap

- Evident that low energy buildings often fail to perform as anticipated due to modelling assumptions, build quality, commissioning, handover and operation, and crucially the understanding and motivation of occupants.
- Building performance evaluation (BPE) studies provides a means to identify the gap and its likely causes, fine-tune performance and informing future building design, specification.
- **However** most of the BPE/POE studies are case-study based (contextual), so findings are difficult to compare and generalise.
- Focus has been on assessing the difference between 'as designed' (predicted) and 'as built' (no occupants) performance.
- Despite the recognition that occupant related factors influence energy use, these have not been explored in great depth.



Energy

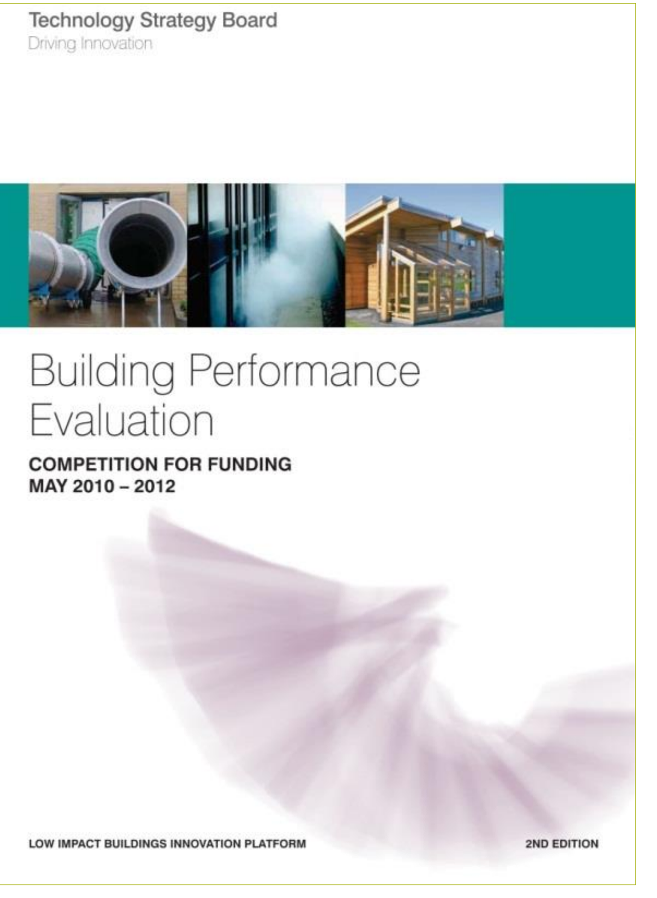
Meta-study: Innovate UK domestic BPE projects

- Assess the magnitude and extent of the gap between predicted and in use energy performance of new ‘low energy’ dwellings, using a meta-study approach (cross project analysis).

- Examine influence of occupancy-related factors on measured energy use using statistical analysis.

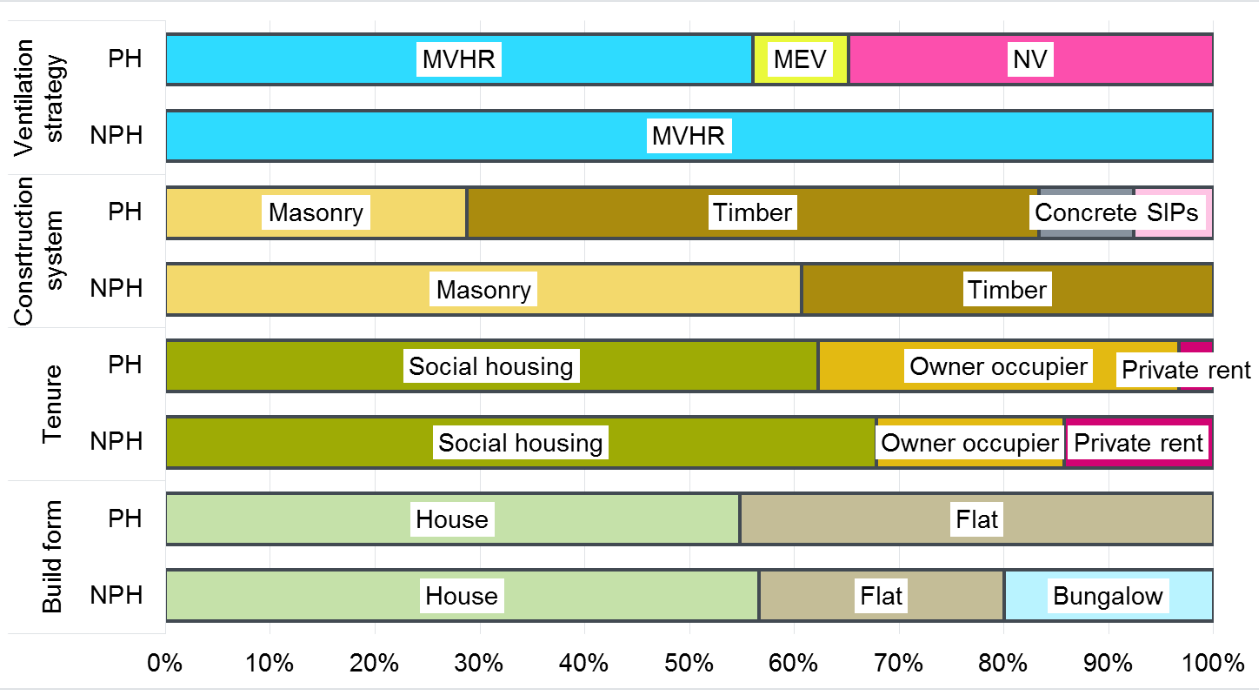
- Database for meta-study built using outputs from the £8 million UK’s National research programme on BPE (2010-2014).

- 53 domestic projects (ultra/low energy) in which 350 dwellings assessed
    - including flats, bungalows and houses
    - representing developments of 3,625 dwellings in total
    - Social housing most common tenure.



Meta-study database: dwelling characteristics

- Data from 92 low energy dwellings (28 developments)
- 30 Passivhaus (6 bungalows, 7 flats and 17 houses)
- 62 Non- Passivhaus dwellings (28 flats and 34 houses) built to contemporary low energy standards such as 'Eco Homes' and 'Code for Sustainable Homes'



	All dwellings	Passivhaus	Non-Passivhaus
Physical Characteristics	**92**	30	62
SAP and measured space heating energy	**62**	12	50
SAP and measured energy use	**57**	14	43
End uses of energy	**48**	9	39

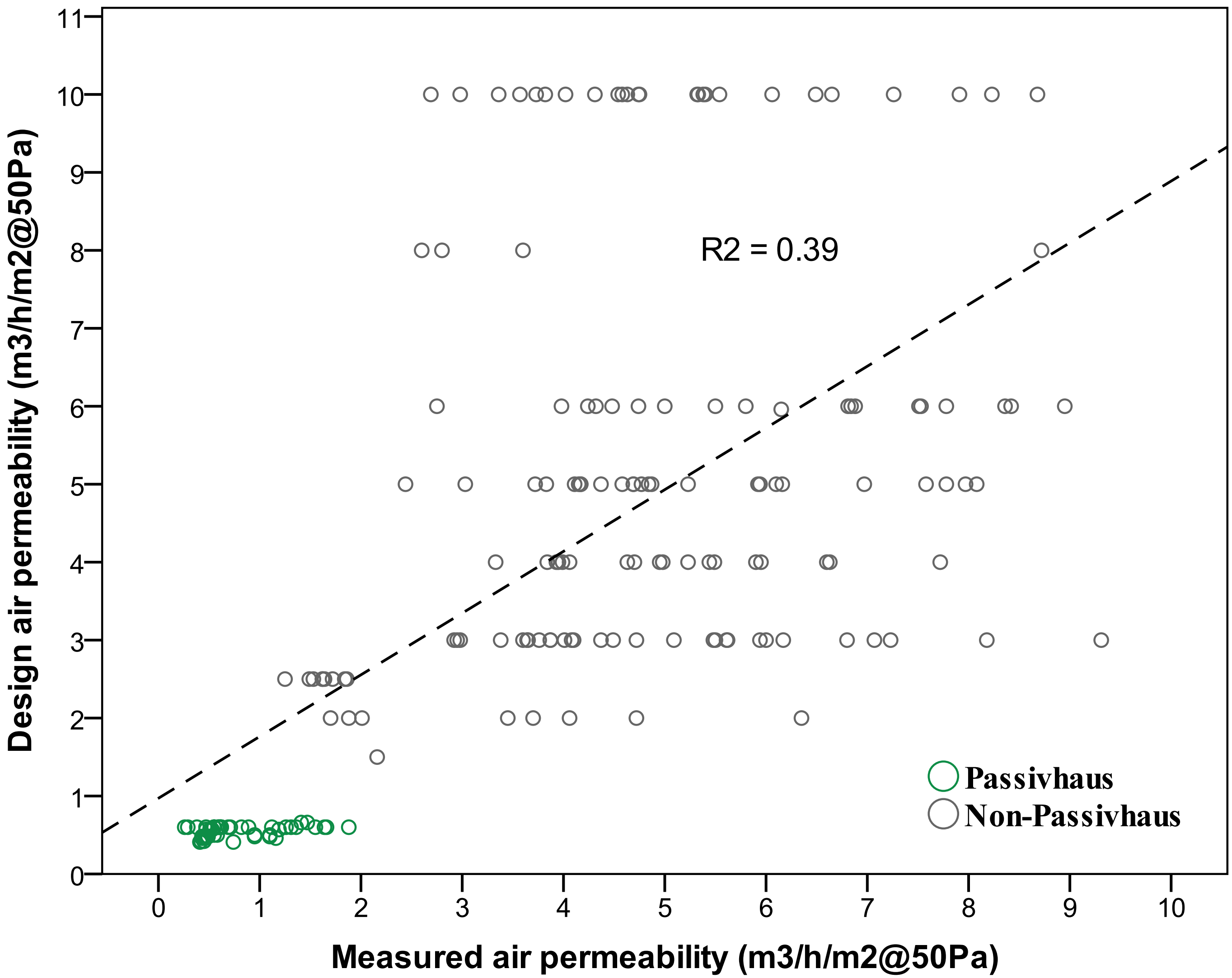
Meta-study database: Designed and measured air tightness

Design air permeability

- Mean: 4.0 $m^3/h/m^2$@50Pa
- Median: 3.0 $m^3/h/m^2$@50Pa

Measured air permeability

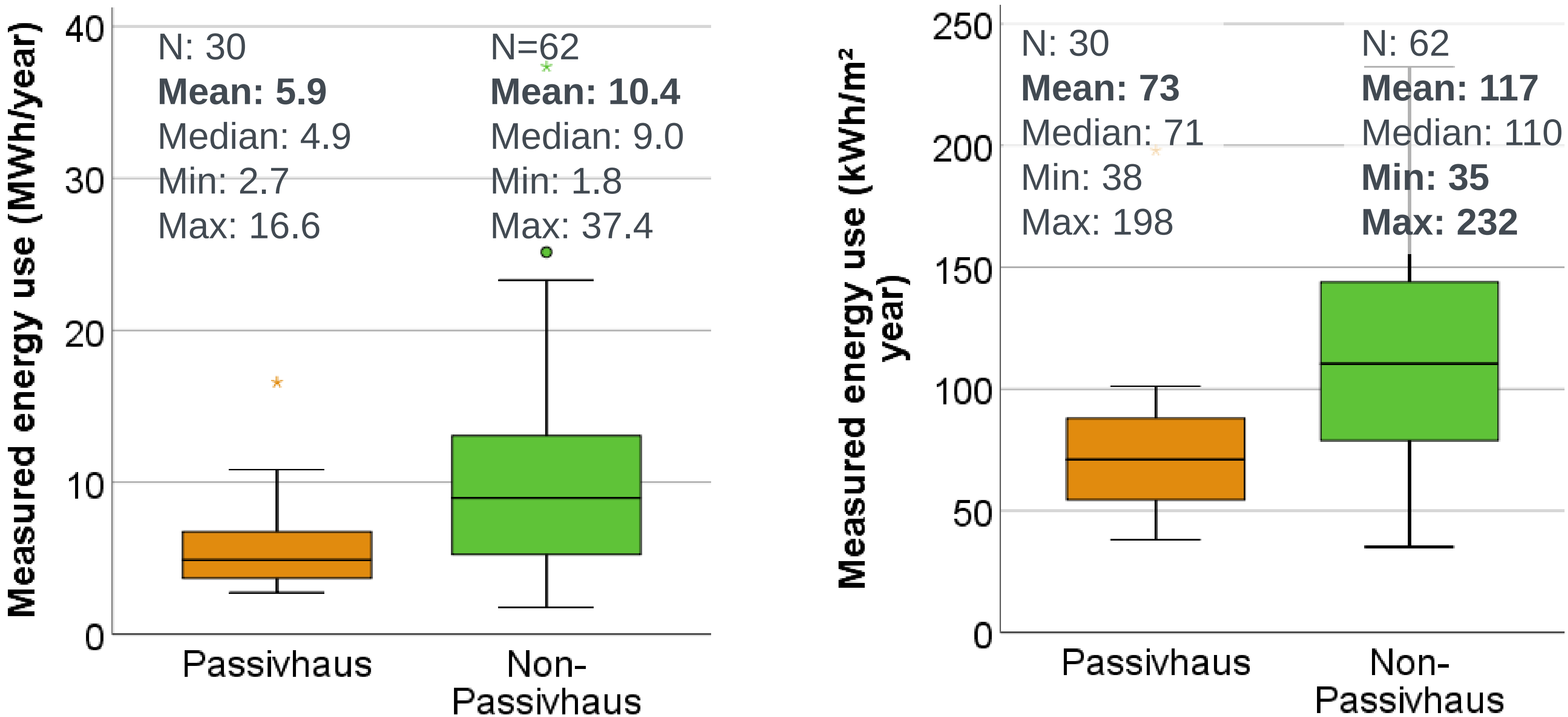
- Mean: 3.8 $m^3/h/m^2$@50Pa
- Median: 4.0 $m^3/h/m^2$@50Pa



Findings

Measured energy use and energy performance gap

Measured energy use



- **Measured** annual energy consumption range: **35-232** kWh/m^2/year
- Overall mean**:** 103 kWh/m^2/year (2013 UK national average)
- Mean annual energy use: 73 kWh/m^2/year for PH dwellings and 117 kWh/m^2/year for NPH dwellings.
- PH dwellings on average used 60% less energy use than NPH dwellings

Predicted and measured energy use

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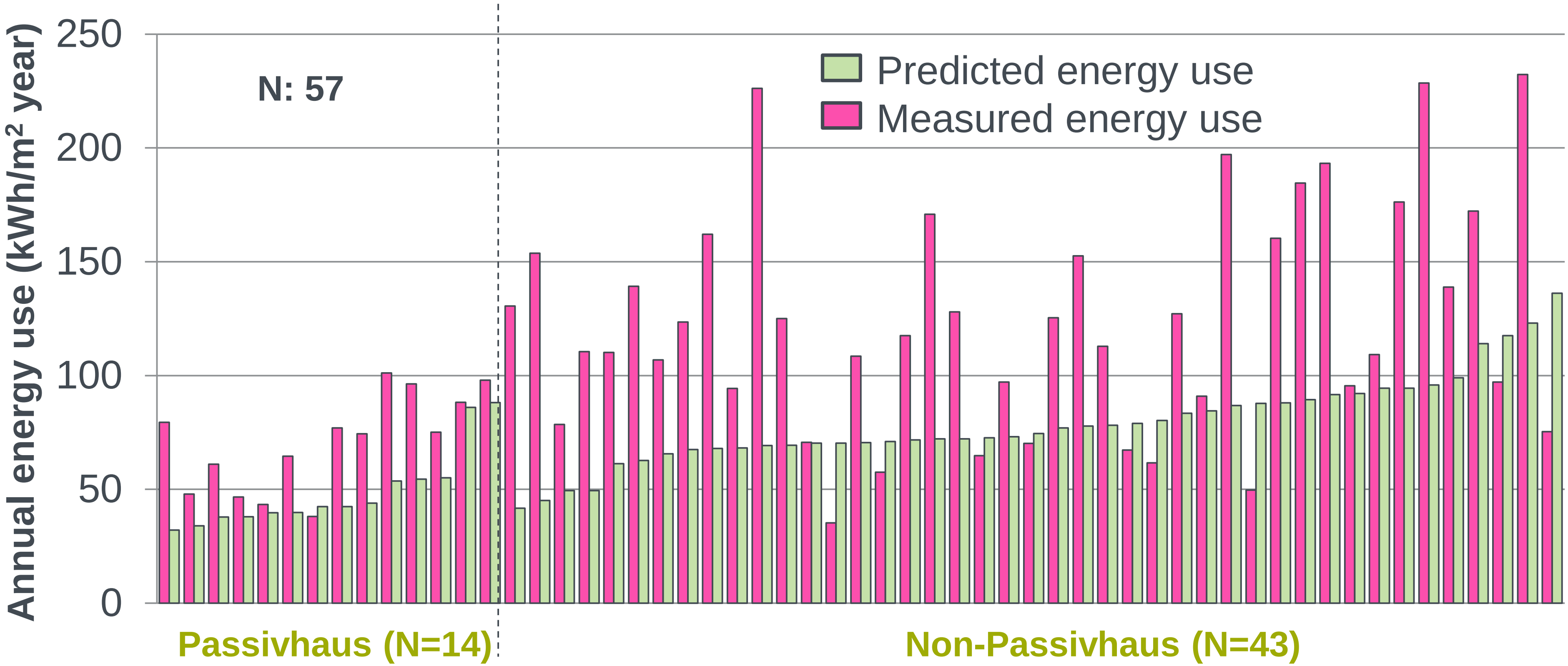
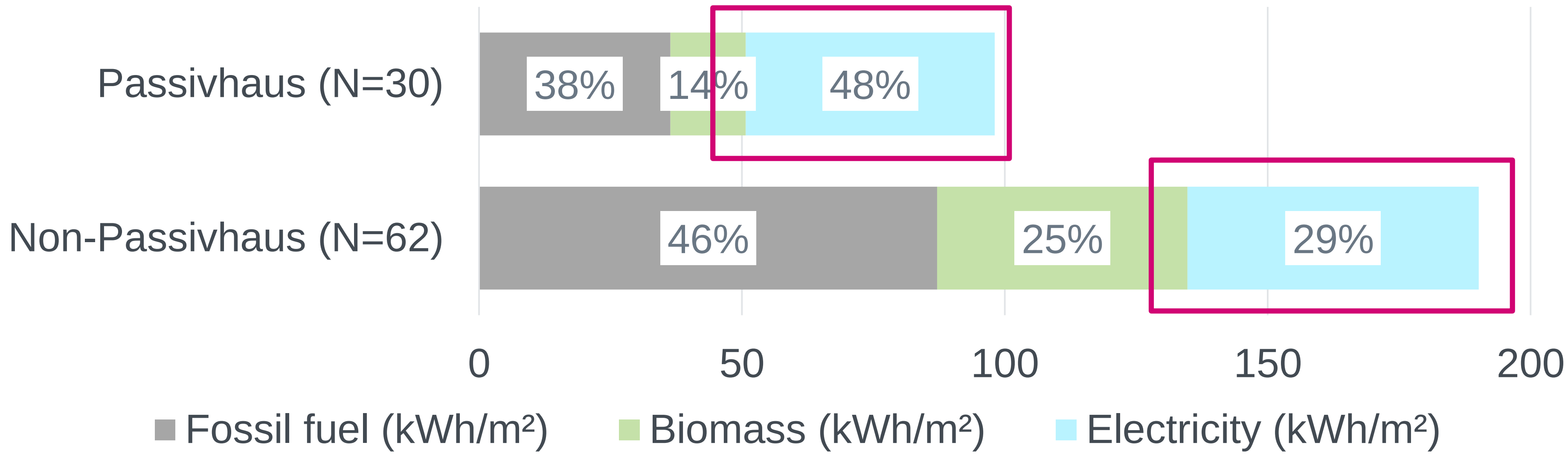


- Measured energy > Predicted energy in 13 PH and 35 NPH dwellings
- No statistical relationship between predicted and measured energy use
- On average measured energy was 50% (PH) and 63% (NPH) more than predicted
- Average performance gap: 22 kWh/m^2/year (PH) and 45 kWh/m^2/year (NPH)

Measured energy use by energy vector



- PH dwellings used much less fossil fuel and biomass per m^2 than electricity (non-heating) because of their high thermal standards.
- NPH dwellings used a considerably higher amount of fossil fuel compared to electricity and biomass.
- Mean electricity use was similar between PH (47 kWh/m^2) and NPH (55 kWh/m^2) dwellings sample.

Measured energy use by end use

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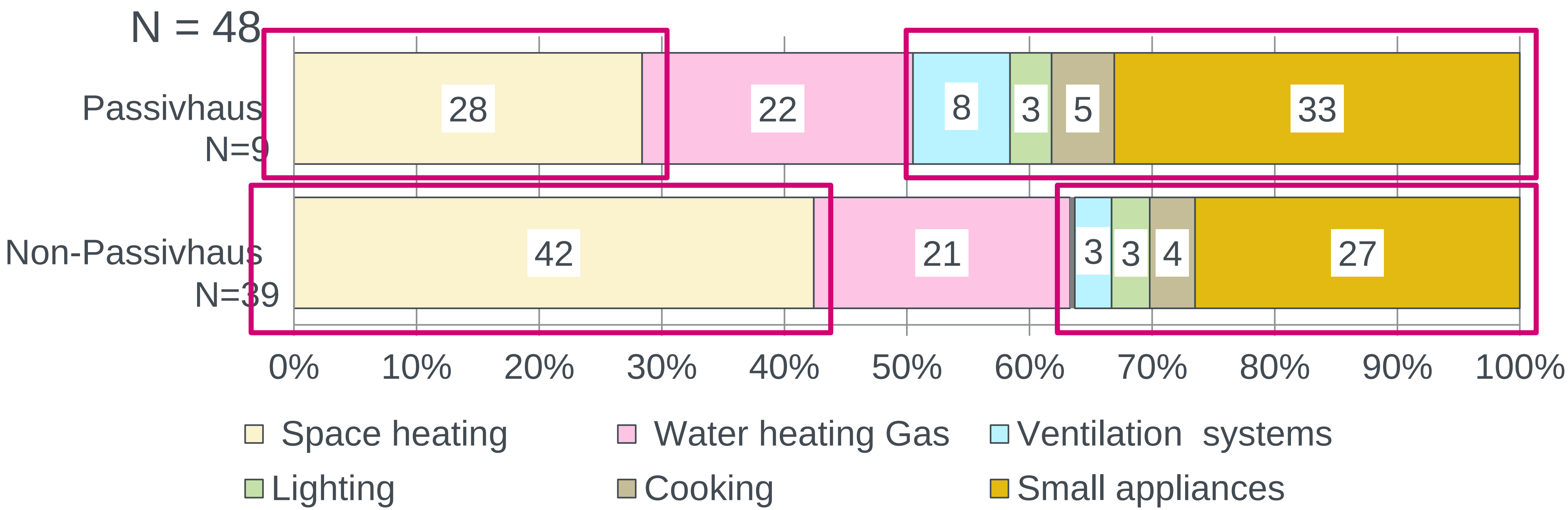
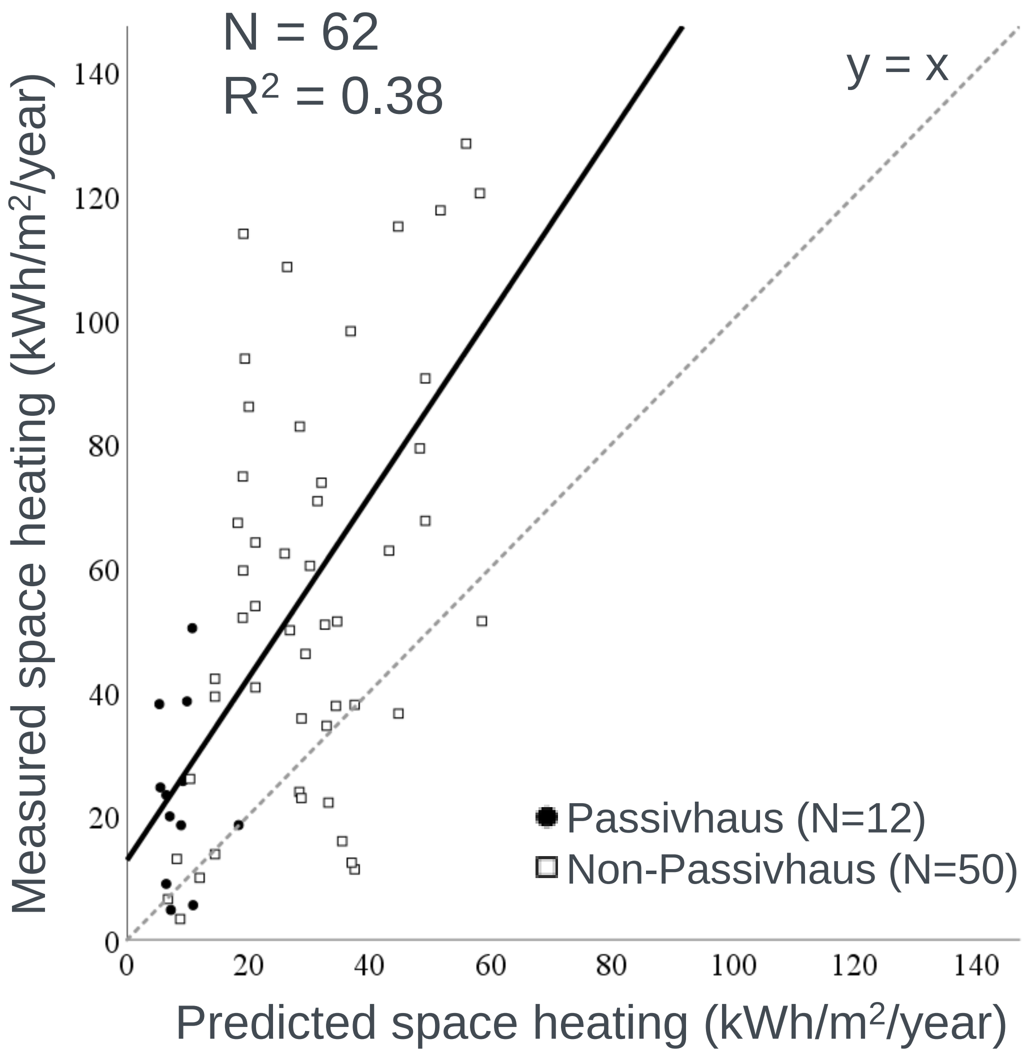


- Space heating still largest end use despite being low energy dwellings:
  - On average 28% of total energy going up to **52%** (PH)
  - On average 42% of total energy going up to **76%** (NPH)
- Space heating and hot water: **50%** (PH), **63%** (NPH) of total energy
  - UK average is **80%** (**62%** space heating + **18%** water heating)
- Unregulated energy use - Cooking + Small appliances accounted for on average 38% of total energy in PH and 29% in NPH dwellings.
- Highlights the impact that the number, type and use of appliances can have on total energy use

Space heating: Predicted vs. measured

- Relationship between predicted and measured space heating energy was weak but statistically significant.
    - $R^2 = 0.29$ in NPH
    - Results not statistically significant for PH dwellings
- Measured space heating was nearly double the predicted space heating in NPH and three times more in PH
- **However** the magnitude of the space heating energy gap was much lower in PH (14 kWh/m²/year) compared to NPH (28 kWh/m²/year)



Findings

Influence of occupancy related factors

Number of occupants and measured energy use

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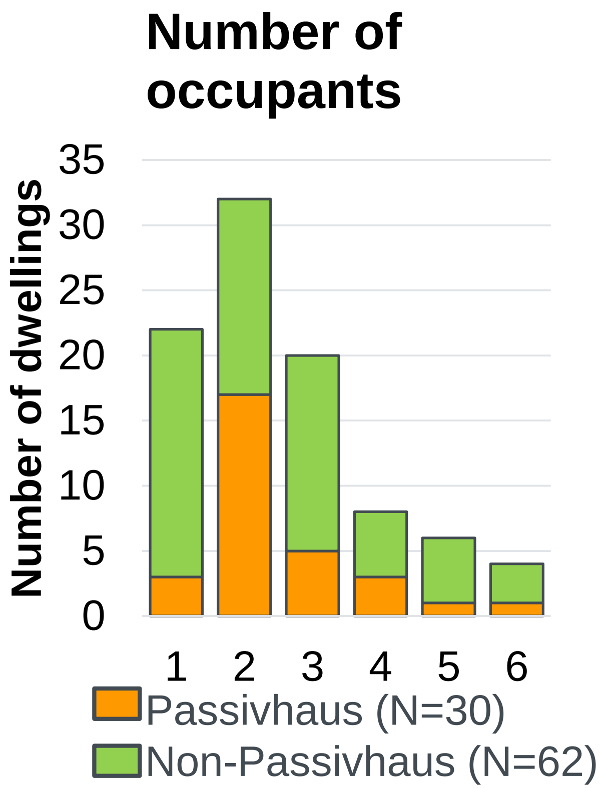
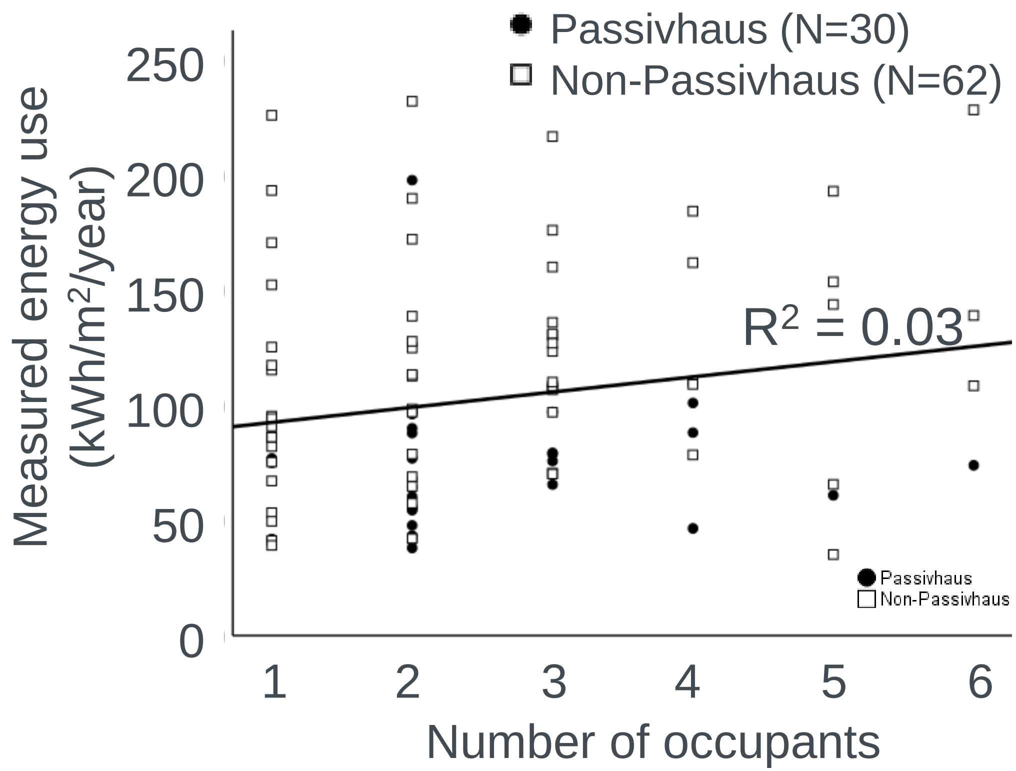
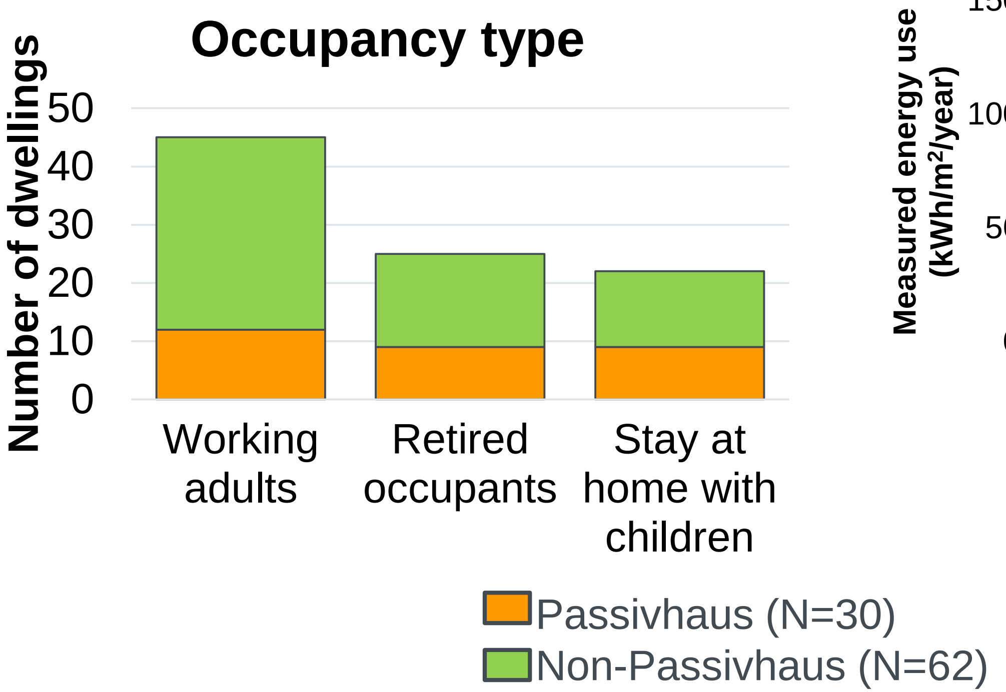
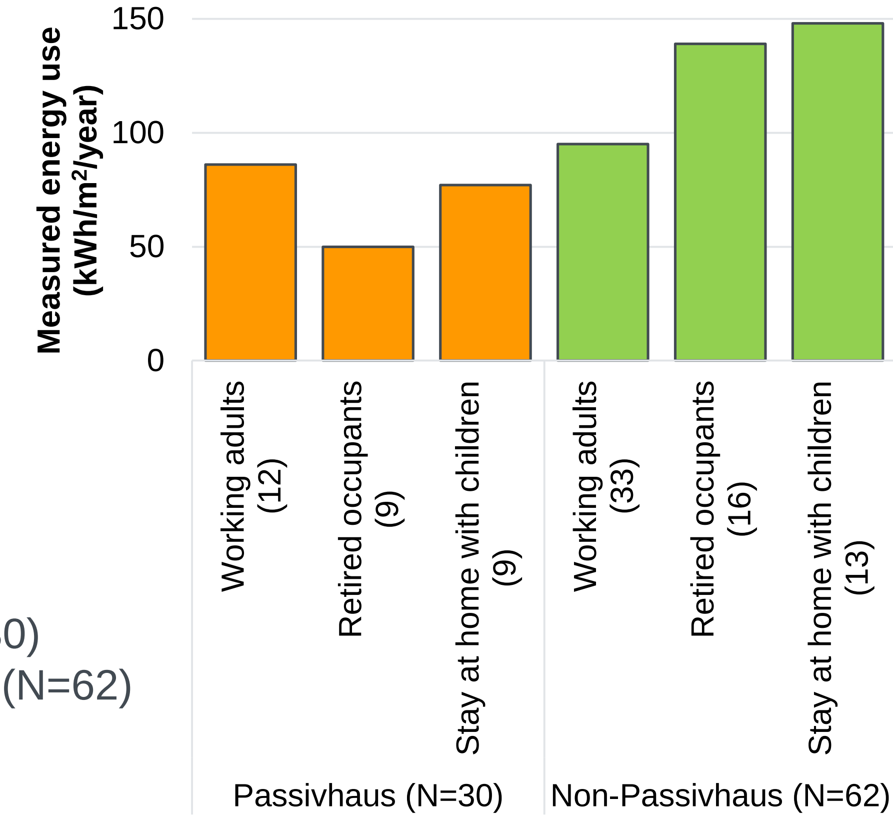




- Number of occupants had little impact on measured energy use for PH and NPH dwellings.
- Regression analysis implied that for each additional occupant, the average energy consumption would increase by 6.7 kWh/m²/year (PH) and 7.8 kWh/m²/year (NPH)

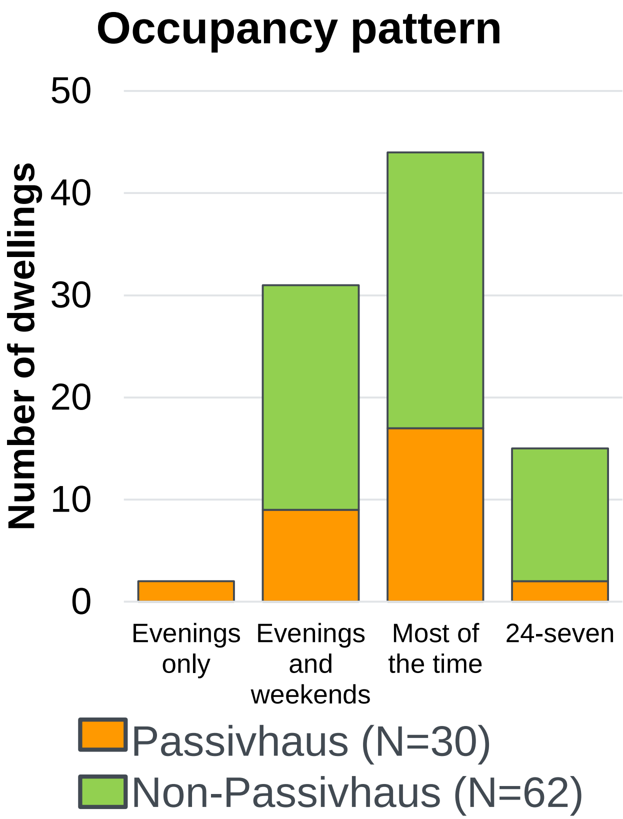
Occupancy type and measured energy use

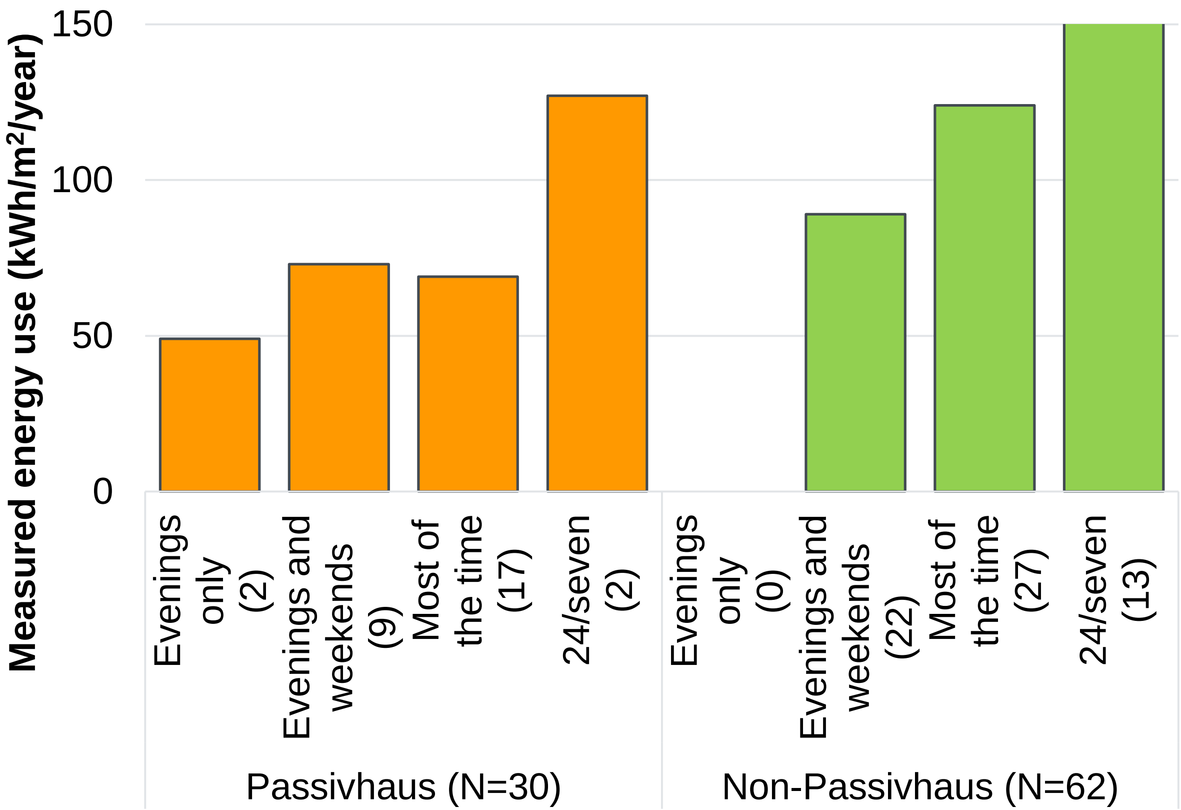




- Occupancy type had a significant impact on total energy use.
- Occupants who *stayed at home with children* used an average of **119** kWh/m^2/year compared to **107** kWh/m^2/year for *retired occupants* and **92** kWh/m^2/year for *working adults*.
- In PH dwellings, working adults used slightly more energy per m^2 than retired occupants and occupants that stayed at home with children

Occupancy pattern and measured energy use





- The more time occupants spent in dwellings, the greater the energy use was.
- In PH dwellings, measured energy use for ‘*24/7’ occupancy* was 84% higher than ‘most of the time’ and 73% higher than ‘evenings and weekends’
- In NPH dwellings, measured energy use for *’24/7’ occupancy* was 22% higher than ‘most of the time’ and 70% higher than ‘evenings and weekends’

Occupancy factors and measured energy use

- Combination of number of occupants, occupancy type and occupancy pattern explained **45%** of variation in measured energy use.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics: R Square Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
1	.449[a]	.201	.174	44.33018	.201	7.397	3	88	.000	1.494

a. Predictors: (Constant), Occupancy Pattern, Number of occupants, Occupancy type

b. Dependent Variable: Measured energy use (kWh/m2 year)

- Regression model (significant at $p<0.01$) developed to compare the relationship between the three occupancy related variables and measured energy use

- Occupancy pattern (i.e. how often the dwelling was occupied) was found to have the largest contribution to the variance in measured energy use.

Coefficients[a]

Model		Unstandardized Coefficients: B	Std. Error	Standardized Coefficients: Beta	t	Sig.	95.0% Confidence Interval for B: Lower Bound	Upper Bound
1	(Constant)	17.127	20.200		.848	.399	-23.017	57.270
	Number of occupants	2.400	3.621	.067	.663	.509	-4.796	9.596
	Occupancy type	.997	6.461	.017	.154	.878	-11.844	13.837
	Occupancy Pattern	27.607	7.158	.418	3.857	.000	13.381	41.832

a. Dependent Variable: Measured energy use (kWh/m2 year)

Occupancy factors and energy performance gap

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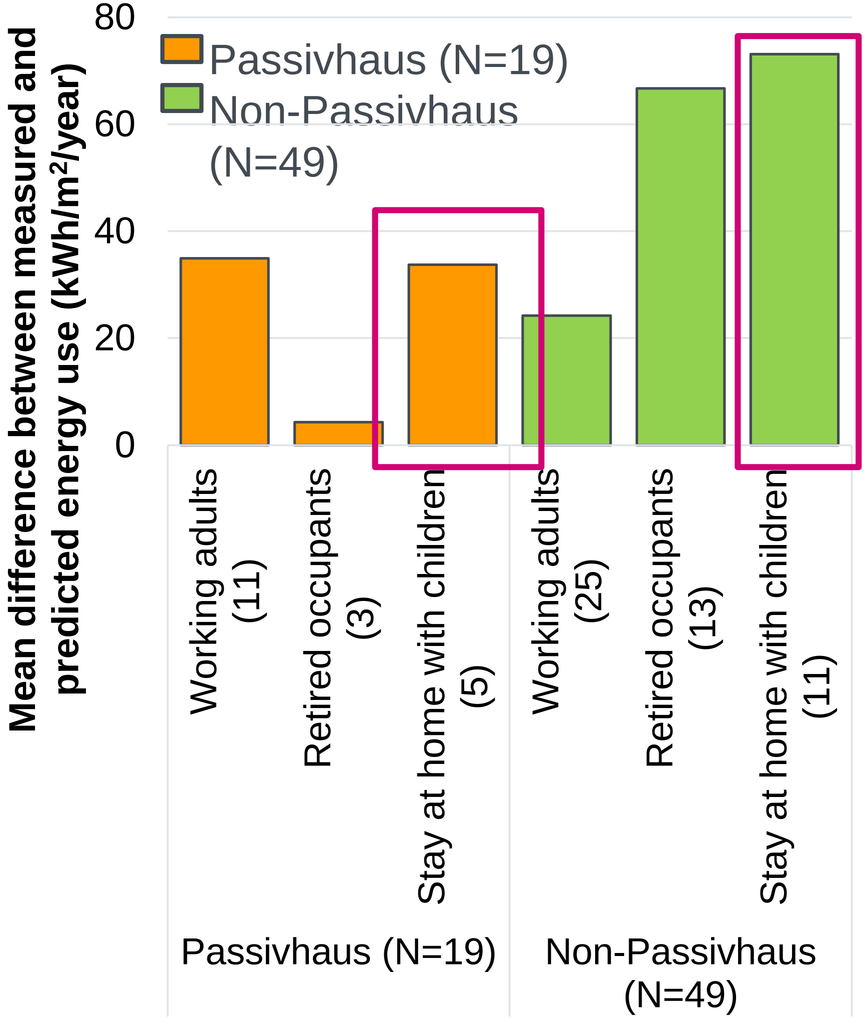
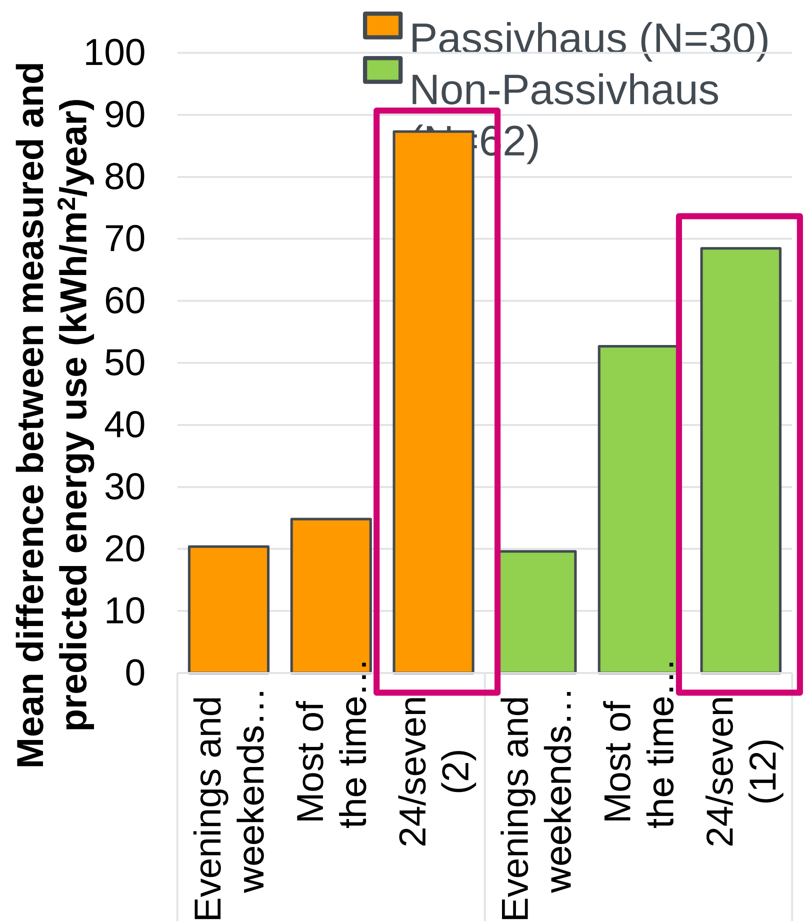


- Type and pattern of occupancy contributed to EPG
- *Stay at home/ retired occupants* with *24/7 occupancy* were associated with the greatest EPG.



Implications for policy

- UK Building Regulations currently address building fabric and efficiency of the heating system:
  - Occupancy related factors are also important in determining space heating demand and should therefore not be overlooked.
  - Unregulated energy use (small appliances, cooking) becomes a significant proportion as thermal standards improve, and should be included in Building Regulations.
  - Move from as-built performance (without occupants) to in-use energy performance of dwellings.

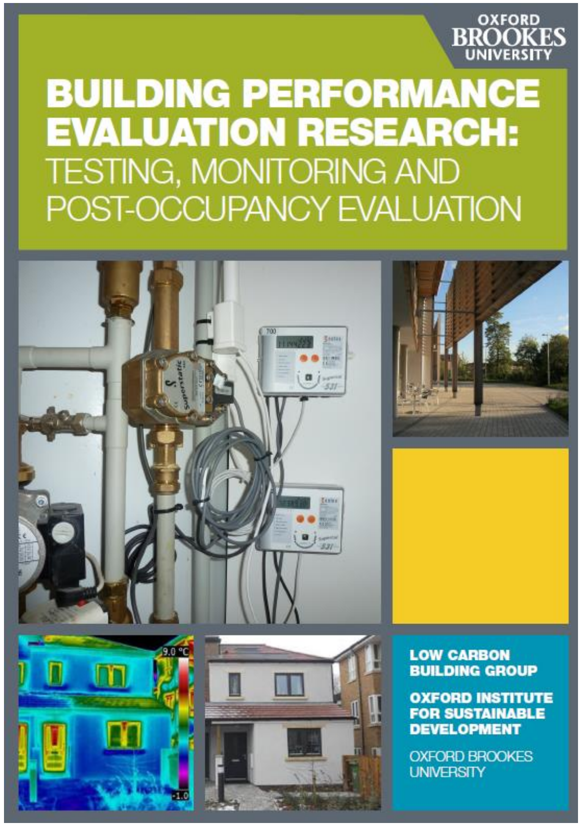
- Developing alternative metrics to energy per square meter. To include *occupancy pattern* (hours that building is occupied), energy use could be normalised as kWh/m^2/hour of occupation.
  - Compare a dwelling occupied for 80% of time and uses 80 kWh/m^2/year vs a dwelling occupied for 50% of time and uses 50 kWh/m^2/year.

- Performance gap in space heating energy was found to be prevalent across the majority of dwellings in the sample. This trend may change with electrification of heat especially through heat pumps if they are installed, commissioned, operated and controlled properly.

Conclusions

- **Gap** between predicted and measured energy use was found to be **prevalent** even in high performing low energy dwellings.
- **Space heating** makes up a significant proportion of the overall energy use in both PH and non-PH dwellings, despite being designed to thermal standards being high (Mean air permeability was 4 $m^3/h/m^2$@50Pa)
- **Unregulated energy use** for cooking and small appliances makes up a **significant** proportion of overall energy use in low energy dwellings, and cannot be overlooked in Building Regulations.
- **Occupancy related factors** have a significant influence on actual energy use, and should not be overlooked.
- Most important occupant-related factor influencing overall energy use is not the number of occupants, but rather the **type of occupants** and even more so the **occupancy pattern**.
- It is essential that occupancy related factors are considered in any future **analysis of dwelling energy use** (models simulating occupancy) and **Building Regulations** (making BPE/POE studies mandatory).

Thank you for your attention!



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