Investigating the Impact of Housing Energy Efficiency on Indoor Environment at the Overheating Summer – A Study in Southwark, London

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Summary

This study investigates the impact of housing energy efficiency on summer overheating. Using indoor sensor data, energy performance certificates (EPC), and household surveys, it explores temperature variation among energy efficiency levels and the existence of communal heating. Applying two-sample t-tests, results reveal that energy-efficient homes could "trap" heat for good insulation, while inefficient ones experience fluctuating temperatures in Southwark, London. Moreover, the non-adjustable communal heating deteriorates summer heat. These findings suggest future energy retrofit practices as well as policies to adapt to overheating, by adopting better ventilation systems, adjustable communal heating systems as well as scientific EPC rating systems.

KEYWORDS: Housing Energy Efficiency, Communal Heating, Indoor Environment, Summer Overheating, Energy Performance Certificates (EPC)

1. Introduction

The acceleration of climate change leads to ongoing increase in global temperature and more extreme weather events, raising an upcoming and urgent issue for countries that previously had mild summer climate such as the UK. Given the historical reasons, UK homes are not fit for the future needs of adaptable to high temperatures (Climate Change Committee, 2019). With averagely 90% of time spending indoor for most of the people (George and Sarah, 2023), residents are in risks of housing overheating which could threaten their physical/mental health (White-Newsome *et al.*, 2012; Vardoulakis *et al.*, 2015).

Various policies and measures are set for building energy efficiency renovation in the UK. To improve the transparency and awareness of buildings' energy performance, Energy Performance Certificates (EPCs) are issued to provide the energy efficiency information of homes usually by displaying the energy bands ranging from band A (most energy-efficient) to band G (least energy-efficient). Also, UK government invests in communal heating networks through the Heat Network Transformation Programme (HNTP), to transform heating to an energy efficient option. However, these policies and associated energy retrofits are primarily motivated by tackling needs for cold winter instead of hot summer in the UK. The impact of current energy efficiency of housing during summer overheating is seldom highlighted.

Therefore, this study aims to use indoor sensor measurement data to understand how the housing energy efficiency conditions influence the indoor environment in the summer, using the Southwark area in London as study area.

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2. Study Area and Data

The study area is chosen to be Southwark, London (Figure 1). Southwark was one the hottest places in the UK in 2021, and possesses one of the highest number of residents warmed by communal heating at around 17,000 homes (Dahaba, 2023). Furthermore, living in the 12th most deprived borough in London according to the Index of Multiple Deprivation (IMD), Southwark's residents would be highly vulnerable to summer overheating due to limited resources for cooling.

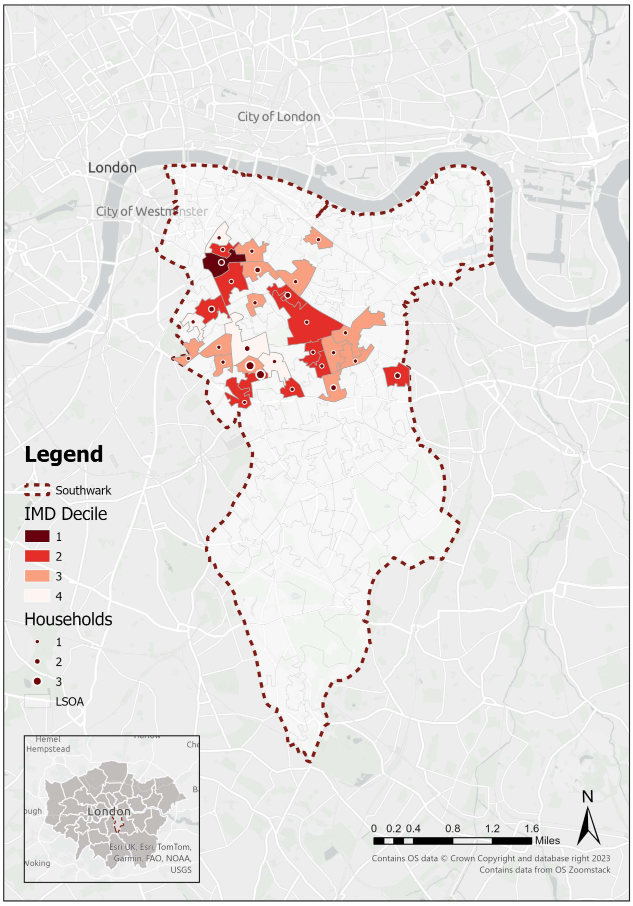


Figure 1 Study area and chosen neighbourhoods (shown in the level of Lower Layer Super Output Areas).

The data collected for this study (Zhao et al., 2023) follows a sensor-enhanced survey approach. Data obtained consist of four parts: (1) indoor sensor measurement data mainly include air temperature, relative humidity, and air quality such as PM levels, (2) local weather station data, (3) individual household survey data and (4) open-source Energy Performance Certificate (EPC) data. First, the indoor sensor measurement data is collected every minute in 40 homes in Southwark from late July to early September 2023, using the Smart Citizen Kit sensor (Smart Citizen, 2018). Second, the outdoor weather measurement was obtained from a nearby local weather station – LIMBO (Met Office WOW, 2022). It includes continuous climate data such as air temperature, relative humidity, and wind speed data at the interval of five minutes. Furthermore, survey data was collected from each household in each week during the sensor data collection period, including basic socio-demographic information, housing information (e.g. existence of communal heating systems) and heat-health related questions. Finally, the EPC data of each house are retrieved (OpenDataCommunities, 2023) if existed for the participants' home addresses, which include energy efficiency ratings and other housing energy efficiency-related information.

3. Methods

Hypothesis testing is applied to explore the difference of indoor housing environment across different housing energy efficiency conditions and communal heating systems. There are two null hypotheses to test:

(1) H_{01}: There is no difference between the indoor temperature among homes with different energy efficiency.
(2) H_{02}: There is no difference between the indoor temperature of homes with or without communal heating system.

In our tests, there are four groups in housing energy efficiency (i.e., EPC B/C/D/E) and three groups in communal heating systems (i.e., communal heating system on, communal heating system off, no communal heating system). And we compare the mean, maximum, minimum, and the standard deviation (std) of the indoor temperature for all the groups.

We use the *two-sample t-test* to identify the significant difference between groups. This typically applies to two groups mean comparison (Haslwanter, 2016).

Technically, the *two-sample t-statistic* (T) is calculated as follows:

$$T = \frac{\overline{x_1} - \overline{x_2}}{S_p(\sqrt{\frac{1}{n_1} + \frac{1}{n_2}})} \quad (1)$$

$$S_p = \sqrt{\frac{(n_1-1)s_1^2 + (n_2-1)s_2^2}{n_1+n_2-2}} \quad (2)$$

Specifically, $\overline{x_1}$ and $\overline{x_2}$ stand for average values of each group, n_1 and n_2 represent the sample size of each group, s_1^2 and s_2^2 are the variance of each of the sample sets. The interpretation of t-score includes looking up the t-table to find its p-value, which indicates if the mean difference between the two sample is statistically significant.

4. Results

4.1. Descriptive statistics

The distributions of homes across different groups of energy efficiency and communal heating systems are shown in Table 1. We can match 33 out of 40 addresses from the EPC database, and only 25 households provided the communal heating system information in the household survey. Interactively, 22 households have available data for both (Figure 2).

Table 1 Statistics of Energy Efficiency and Communal Heating Homes.

Category	Variable	Count
Energy efficiency (N=33)	EPC B	12
	EPC C	9
	EPC D	8
	EPC E	4
Communal heating (N=25)	'No'	15
	'Yes-summer on'	5
	'Yes-summer off'	5

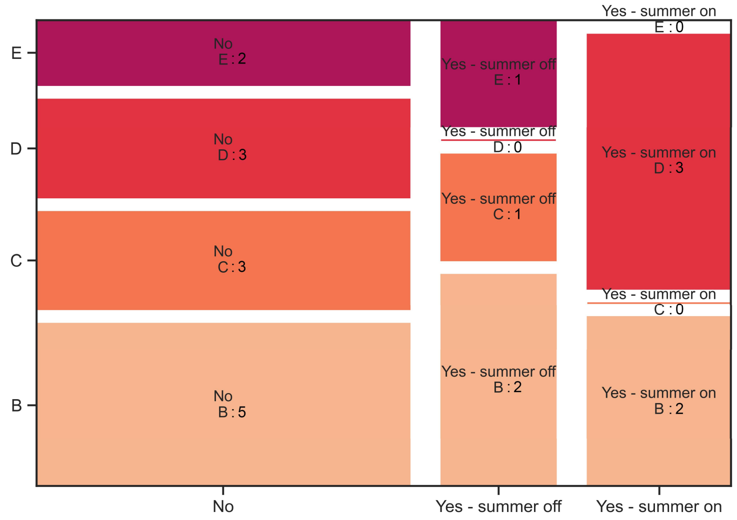


Figure 2 Interactive distribution of energy efficiency groups and communal heating groups.

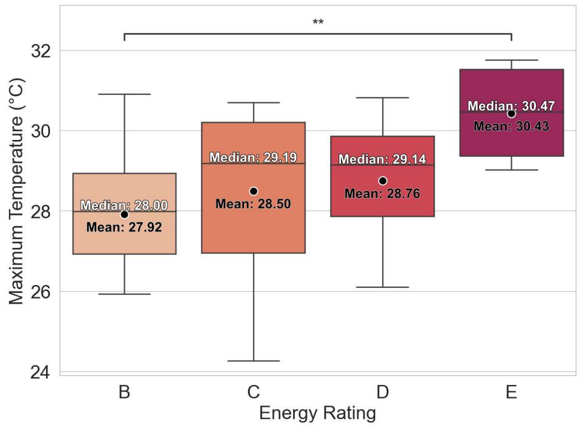
4.2. Two-sample t-tests

We have applied two-sample t-tests for each paired group (the energy ratings are paired with each other in 6 paired groups) to explore the difference between them. According to Table 2, it is obvious that homes with poorer energy efficiency generally have higher maximum temperature and lower minimum temperature, along with more fluctuant temperature. Specifically, statistically significant difference of maximum temperature is found for EPC B and EPC E houses and the EPC E houses have 2.5 Celsius degree higher average maximum temperature in the entire study period (Figure 3a). For minimum temperature, EPC E homes are about average 2.35 Celsius degree lower than EPC C/D houses with statistically significant evidence (Figure 3b). Furthermore, temperature standard deviation sees difference between EPC B/C and EPC E houses at around 0.7 Celsius degree with remarkably significant evidence (Figure 3c).

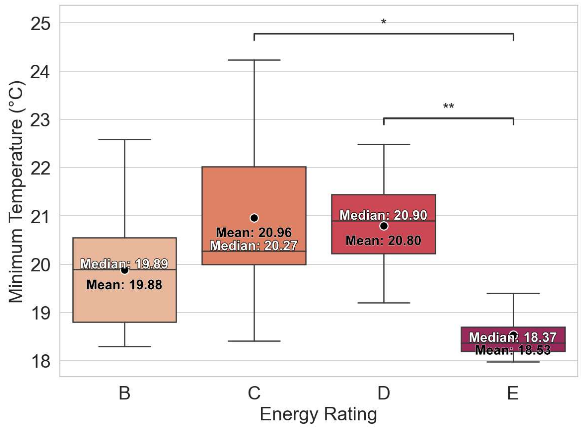
Table 2 Results of Two-sample T-test for Energy Efficiency (t-score and p-value).

	Mean temperature	Maximum temperature	Minimum temperature	Temperature std
B vs C	-0.29 (0.77)	-0.72 (0.48)	-1.48 (0.15)	-0.85 (0.41)
B vs D	-0.65 (0.52)	-1.17 (0.26)	-1.55 (0.14)	-1.19 (0.25)
B vs E	0.34 (0.74)	-3.00** (0.009)	1.85 (0.09)	-5.53** (7.41e-05)
C vs D	-0.18 (0.86)	-0.26 (0.79)	0.21 (0.83)	-0.44 (0.67)
C vs E	0.44 (0.67)	-1.59 (0.14)	2.37* (0.04)	-3.24** (7.85e-03)
D vs E	1.44 (0.18)	-1.70 (0.12)	3.68** (0.004)	-1.97 (0.08)

NB: * denotes significance at the 0.05 level, ** at 0.01 level.



(a)



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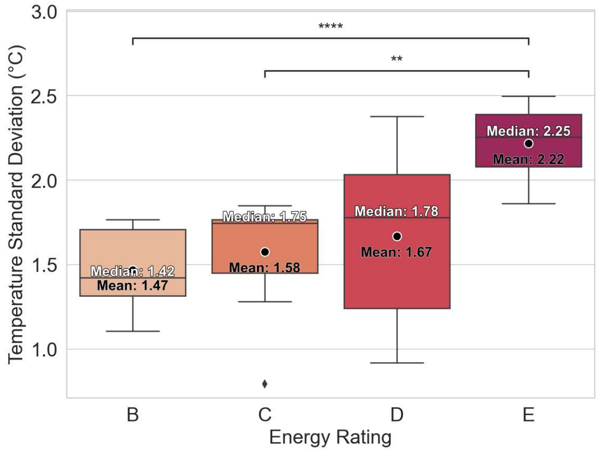


(c)

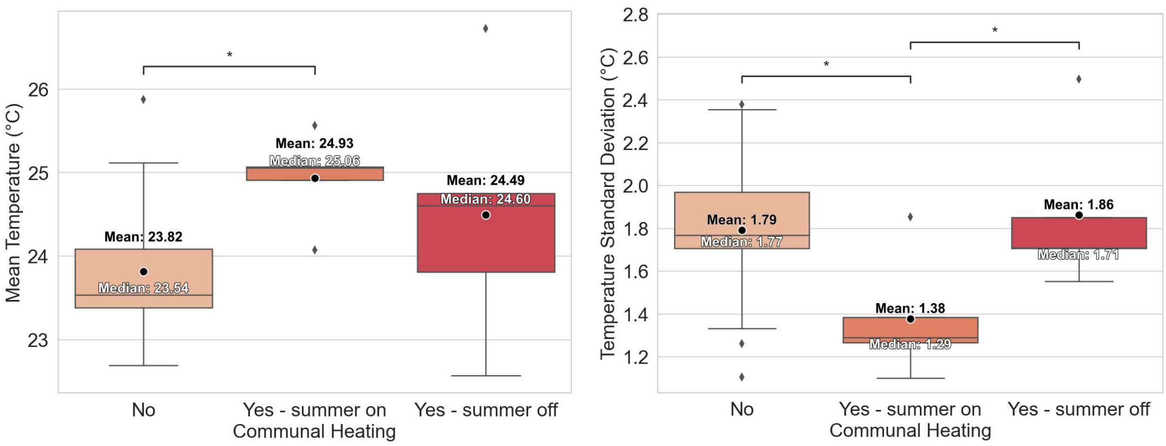
Figure 3 Indoor temperature comparison among different energy efficiency groups.

On communal heating system comparison (Table 3), statistically significant mean temperature difference is found at 1.1 Celsius degrees between households without communal heating system and households that cannot turn the communal heating system off (Figure 4a). Also, homes without communal heating are found to experience more fluctuant temperature (approximately 0.4 Celsius degrees) compared to those with communal heating on during summer (Figure 4b).

Table 3 Results of Two-sample T-test for Communal Heating (t-score and p-value).

	Mean temperature	Maximum temperature	Minimum temperature	Temperature std
No vs Summer on	-2.81** (0.01)	0.29 (0.78)	-1.22 (0.24)	2.27* (0.04)
No vs Summer off	-1.28 (0.22)	-0.63 (0.54)	-0.37 (0.71)	-0.37 (0.71)
Summer on vs Summer off	0.61 (0.56)	-0.74 (0.48)	0.39 (0.71)	-2.32* (0.05)

NB: * denotes significance at the 0.05 level and ** at 0.01 level.



(a) (b)

Figure 4 Indoor temperature comparison among communal heating groups.

Overall, it is found that energy efficiency mainly affects indoor temperature fluctuations, which is reasonable as energy efficient homes are usually well-insulated. While the temperature in energy efficient homes is more stable, absorbed heat could 'trap' inside making homes hard to cooldown e.g. during nighttime if there is no effective ventilation measure. Also, communal heating systems primarily influence indoor mean temperature, as a running communal heating will increase the average indoor temperature. Findings also suggest that current EPC rating system does not fit for summer overheating, probably for its emphasis on insultation instead of ventilation. It suggests that there should be a holistic evaluation (e.g. both insulation and ventilation performance) of building energy efficiency in the future.

5. Conclusions

In summary, this study explored the influence of housing energy efficiency and communal heating system on indoor temperature during the summer season, with the support of indoor environmental sensors. The results find energy efficient homes have significantly less fluctuant indoor temperature, confirming the assumption that they could "trap" heat inside if there is no effective ventilation during the summer. We also find the non-adjustable communal heating system could make homes hotter in summer. To tackle extreme hot and extreme cold weather at the same time, future UK homes will require adaptable energy retrofit practices and policies. These include better ventilation systems, adjustable communal heating systems, and scientific EPC rating systems.

6. Acknowledgements

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7. Software and Reproducibility

All the code to conduct data pre-processing, analysis and visualization in this research is available through GitHub (https://github.com/YunbeiOu/HousingSensorsUrbanHeatInvestigation).

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Biographies

Yunbei Ou is a second year PhD student in Urban Studies in the Urban Big Data Centre at University of Glasgow, funded by the SGSSS Supervisor-led Steers Studentship. In her PhD project, she endeavors to use urban analytics and advanced modelling methods to facilitate housing decarbonization and housing price estimation.

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