Applied Energy 411 (2026) 127573

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Thermal energy demand database for typical British dwellings☆

Lloyd Corcoran, Pranaynil Saikia, Carlos E. Ugalde-Loo *, Muditha Abeysekera

School of Engineering, Cardiff University, Wales, UK

HIGHLIGHTS

- The database considers ∼220,000 annual thermal demand datasets for UK dwellings.
- Physics-based simulations and typical meteorological year weather data were used.
- Five UK locations and four orientations were adopted for national variability.
- Demonstrated the database use via a community-scale study in Cardiff with peak cooling and heating loads of ∼200kW and ∼260kW.
- The database supports forecasting, energy planning and policymaking for low-carbon housing.

ARTICLE INFO

Keywords:
Building envelope
Climate change
Cooling
Database
Heating
Thermal energy demand

ABSTRACT

Due to the impacts of climate change, the world is experiencing rapidly rising temperatures and shifting weather patterns. In Northern hemisphere countries like the United Kingdom (UK), dual-seasonal thermal energy demand is faced, with intense winter heating needs and elevated summer cooling requirements due to the increasing frequency and intensity of heatwaves. Thus, understanding the changing demand for both heating and cooling is becoming increasingly important towards meeting legally-binding net-zero targets based on how the required additional demand on electricity networks is met. Despite this, most attention has been given to heat demand, with space cooling not receiving significant consideration so far and the intrinsic interdependence between heating and cooling requirements not fully accounted for. In addition, domestic buildings have not been sufficiently investigated, with a substantial focus placed instead on commercial and industrial sites. This paper presents a database of yearly thermal energy demand for typical UK dwellings. The work captures the seasonal variation in thermal demand between warmer and colder months. To this end, typical meteorological weather files, alongside six selected geographical locations, multiple dwelling types, different construction data and four building orientations were considered to create year-round datasets. The database includes approximately 220,000 high-resolution datasets in total, which are provided alongside the paper. Each dataset comprises the hourly thermal energy demand required to maintain a set-point indoor temperature of 21°C either through heating or cooling provision. Internal load profiles considering lighting, appliances and occupancy are made available, which can be further modified and incorporated to the thermal loads. A methodology to adjust internal set-point temperatures to encapsulate a wide variety of thermal comfort levels is also presented. Representative examples demonstrate how the database can be used to support broader analyses of seasonal heating demand while also exploring emerging cooling demand in a warming world.

1. Introduction

Understanding the thermal energy demand in dwellings is important to support countries in reaching their net-zero emission targets, as both heating and space cooling demand directly influence policy-making, energy consumption patterns and strategies for reducing carbon emissions in the domestic sector. For the United Kingdom (UK) this is of relevance as the domestic sector accounts for approximately 27% of the overall energy usage. In an analysis by the Department for Energy Security and Net Zero, it was found that as the average yearly temperatures in the UK rise, the energy consumption in the domestic sector decreases [1]. This is shown in Fig. 1, where the mean air temperature correlates with energy consumption. This effect has been likely caused by the

☆ This article is part of a Special issue entitled: 'APEN 50 Anni(Dr. Wu)' published in Applied Energy.

* Corresponding author.
E-mail address: Ugalde-LooC@cardiff.ac.uk (C.E. Ugalde-Loo).

https://doi.org/10.1016/j.apenergy.2026.127573
Received 13 October 2025; Received in revised form 31 January 2026; Accepted 16 February 2026
Available online 3 March 2026
0306-2619/© 2026 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

Nomenclature

Abbreviations	*Definitions*
ACH	Air changes per hour
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CIBSE	Chartered Institution of Building Services Engineers
EPW	Energy Plus Weather
IES VE	Integrated Environmental Solutions Virtual Environment
ISO	International Organization for Standardization
MAE	Mean absolute error
RMSE	Root mean squared error
TMY	Typical meteorological year
UK	United Kingdom
Symbols	***Definitions***
K_i	Installed light efficacy (Lum/W)
q_i	Lighting load density (W/m^2)
Q_L	Lighting load (W/m^2)
U	Thermal transmittance or U-value (W/(m^2·K))

decreased heating demand in winter over the last years.

Thermal energy demand in the UK has historically been dominated by space heating and heat demand remains the dominant contributor to annual thermal energy use in domestic dwellings. However, with global temperatures rising and both the frequency and intensity of heatwaves increasing, a growing need for space cooling (both passive and active) during the summer months is now being experienced in the country [2]. These needs mark a significant shift in household energy consumption patterns and thus introduce new challenges for electricity grids.

The vast majority of dwellings in the UK housing stock has traditionally been equipped with space heating systems only. As a result, building design, regulations and performance assessments have in general prioritised winter heat demand. However, the more recent growing prevalence of overheating assessments driven by increased summer temperatures has shifted attention towards cooling-related issues. There is thus a delicate interplay between heating and cooling in domestic dwellings, where an increased cooling demand over summer months risks offsetting reductions in heating energy and may place additional strain on local electricity distribution networks during peak summer periods. At the same time, measures and interventions introduced to mitigate overheating and reduce cooling demand in new dwellings can also alter the thermal performance of buildings during winter months, potentially increasing heat demand, and leading to an overall rise in the use of energy for UK households. It is therefore essential that emerging cooling demand is analysed within a whole-year thermal context, where interactions and trade-offs between heating and cooling are explicitly captured rather than considered in isolation.

A relevant example of not anticipating and understanding the rising cooling demand in the UK occurred during the June 2023 heatwave. Coal-fired power plants had to be activated to meet the additional demand imposed on the electricity network due to lack of supply from wind turbines and scheduled maintenance on nuclear plants [3]. In general, a deeper understanding of heating and cooling demand both in the domestic and non-domestic sectors could help network operators predict future peak electricity demand. Such insights may be of great value to inform the government on energy security. For instance, the Electric Engagement and Holistic Transition pathways within the Statutory Security of Supply Report 2024 explore the effects of widespread electrification and the growing demand for electrified heating and cooling [4]. A robust analysis of the emerging cooling demand, in particular, can enhance the understanding of its future impact on local electricity networks, informing strategies to ensure reliability and efficiency of electricity supply.

Reference [5] identifies the most comprehensive dataset for cooling energy consumption in the UK's non-domestic sector. However, to the best of the authors' knowledge, no equivalent dataset exists for the domestic sector, even though a substantial amount of homes are increasingly experiencing overheating and summer temperatures are rising as a result of climate change. This is a critical gap: Approximately 2.9 million homes in England experienced overheating in 2023 [6], up from around 1.5 million in 2018 [7], and this upward trend is expected to continue in the future as the climate warms. Without a representative UK-wide resource which gives importance to both heating and cooling, researchers, policymakers, home developers and building designers may lack a robust evidence base to assess dwelling-level thermal energy demand. This could limit their ability to assess future space cooling needs to achieve thermal comfort, design effective overheating mitigation strategies, balance the seasonal interplay between heating and cooling needs, or understand the implications for electricity distribution networks.

This paper directly addresses the lack of thermal energy demand data for UK dwellings by providing the first comprehensive database of yearly heating and cooling demand for the UK domestic sector. It builds on the authors' own work reported in [8], where a methodology to quantify cooling demand was presented. For that seminal work, a limited number of simulations was conducted to demonstrate the

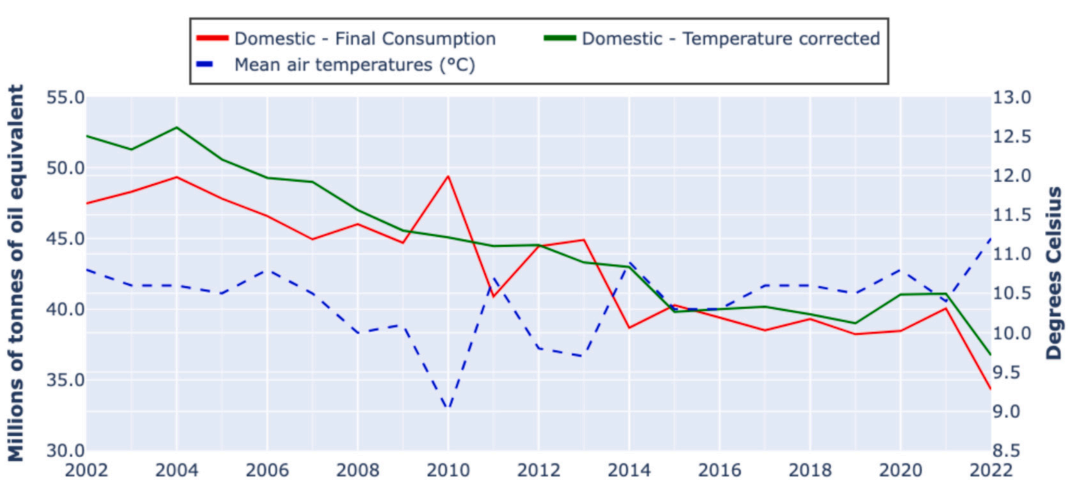


Fig. 1. Domestic energy consumption, temperature-corrected domestic energy consumption, and average annual air temperature in the UK. Figure adapted from data reported in [1].

methodology for selected case studies, with a temporal coverage limited to summer months to showcase cooling performance for a range of UK dwellings. Instead, the main contribution of this paper is the development of an openly accessible, high-resolution, scalable resource of over 220,000 yearly datasets in total that quantifies both heating and cooling demand across different dwelling orientations, locations and the most common dwelling archetypes in the UK according to [9]. This resource is not limited only to the summer period, but considers year-round data—thus facilitating a comprehensive single data source to assess thermal energy demand in a warming climate. The database therefore serves as a nationally relevant evidence base, enabling analyses that were previously not possible due to the absence of consistent domestic-sector data.

The datasets are supported by detailed physics-based modelling and a thorough chronological review on UK Building Regulations and construction materials. The database represents a rich resource offering insight to inform policy-making, enable home developers and engineers to estimate both heating and cooling demand early in the design process, support further research into various fields and empower homeowners to assess and optimise their own thermal demand. The datasets can also support studies on heat electrification by analysing various technologies that can be deployed to meet future thermal demand. Combined with works examining the expected increased demand from electric vehicle uptake [10] and tools like National Grid's Network Capacity Map [11], it may be possible to further inform which electricity network components may need upgrading in the future—thus supporting decision-making for electricity network operators. Given the structure of the database and the methodology employed for its development, it can be further scaled to allow future expansion to additional dwellings, geographical locations and dwelling configurations, including different building orientations and ad-hoc properties of the thermal envelope of buildings.

2. Methods

A methodology to quantify cooling demand in the UK domestic stock was originally introduced in [8] to assess cooling performance over summer months. Such a methodology is summarised by the flow chart shown in Fig. 2. The methodology has been here adopted to develop the thermal energy demand database of typical UK dwellings presented in this paper. This considers year-round energy demand profiles accounting for both warm and cold months, supporting broader analyses of seasonal heating demand while also enabling exploration of emerging cooling demand within a UK context.

This section provides an overview of the thermal energy demand calculation process for typical UK dwellings alongside relevant considerations made to build the database.

2.1. The UK housing stock

As an initial step, an in-depth review into the current UK housing stock was conducted. To this end, relevant results from the English housing survey carried out in 2020 are shown in Fig. 3, which illustrates the age of in-use dwellings in England [9]. As shown in the figure, the majority of UK dwellings were constructed before 1965. Consequently, accurate assessment of their thermal efficiency requires an understanding of the construction methodologies prevalent during earlier periods, particularly those dating from pre-1920 to 1965.

2.2. Construction methods

After determining the age of the dwellings, a detailed review of the construction methods used in the UK throughout the years was performed to assign representative thermal properties to each dwelling archetype. The review aimed to extract thermal transmittance values (commonly known as U-values) for various construction techniques.

In the UK, the Building Regulations define the U-value as a measure of the thermal efficiency of materials—thus enabling standardised

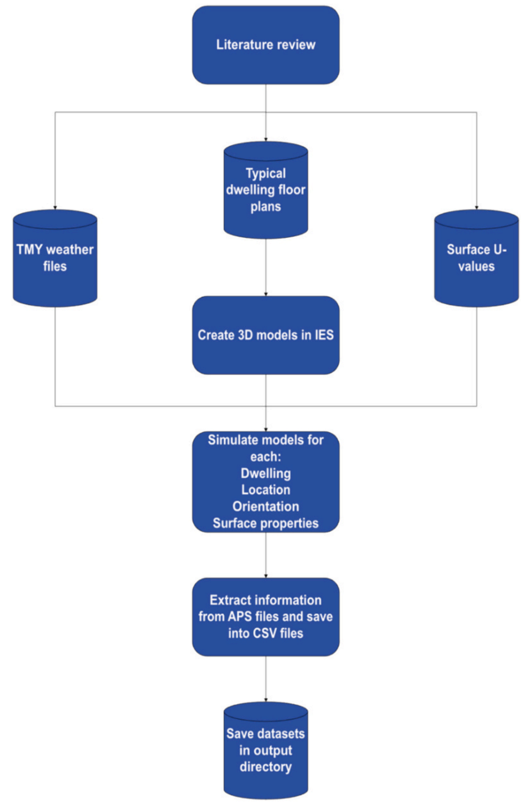


Fig. 2. Modelling framework outlining the methodology to obtain the thermal energy demand of typical dwellings [8].

comparisons. It represents the rate of heat transfer through a material or composite structure [12] and is hence relevant to walls, windows, roofs and foundations. For a given building component, lower U-values indicate better insulation, while higher values signify faster heat transfer. From 1965 to date, U-values have been set as part of the Building Regulations, but beforehand these were calculated based on popular construction methodologies used at the time. For a detailed explanation of their calculation, the interested readers are referred to [13].

The extracted U-values were subsequently used to characterise the thermal envelope of each dwelling type within the database. Key findings from the review of construction methods are summarised in Table 1.

2.3. Typical UK residential dwellings

According to [9], the most common residential dwelling types in the UK housing stock are:

1. Bungalows: These are single-storey residential buildings, typically detached or semi-detached, where all primary living spaces are located on one level.
2. Detached houses: These are standalone residential buildings that do not share any walls with neighbouring properties.
3. Flats: These are individual residential units within a larger multi-storey building, where each dwelling occupies part of a building and commonly shares walls, floors and/or ceilings with other dwellings.
4. Semi-detached houses. These are residential buildings consisting of two adjoining dwellings that share a single common wall but are otherwise separate structures.
5. Terraced houses: These are a series of dwellings constructed in a continuous row, where each dwelling shares side walls with adjacent properties on one or both sides.

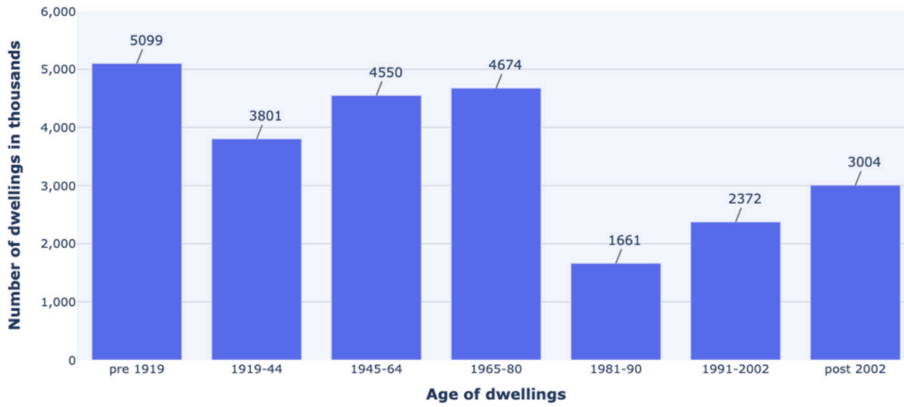


Fig. 3. Age of dwellings in England in 2020 [9].

Table 1
Summarised construction data, adapted from [8].

Year	*U-values* [W/(m^2·K)]			
	Foundations	*Walls*	*Windows/Doors*	*Roofs*
Pre-1920	225 mm concrete slab (≈3.25)	Single layered brick/stone 315 mm (≈1.84)	N/A[1]	N/A
1920	-[2]	Uninsulated cavity walls (≈1.6)	N/A	N/A
1930	300 mm concrete slab (≈2.94)	–	N/A	N/A
1965	Thermal insulation on slab (1.2)	Uninsulated cavity walls (1.7)	N/A	Insulated roofs (1.6)
1970	–	–	Single glazed windows (4.8)	–
1980	–	Insulated cavity walls (1)	–	Insulated roofs (0.68)
1990	–	Insulated cavity walls (0.6)	–	Insulated roofs (0.4)
2000	Thermal insulation on slab (0.51)	Insulated cavity walls (0.45)	Double glazed windows (3.1)	Insulated roofs (0.35)
2010	Thermal insulation on slab (0.22)	Insulated cavity walls (0.3)	Low emissivity double glazed windows (2.0)	Insulated roofs (0.22)
2016	Thermal insulation on slab (0.13)	Insulated cavity walls (0.18)	Argon gas filler (1.6)	Insulated roofs (0.13)
2021	–	–	Double glazed low emissivity with argon gas filler (1.2)	Insulated roofs (0.11)

[1] Due to the surface life expectancy, these values have not been recorded.
[2] Entries with a hyphen (i.e. '-') denote no change from the previous values.

To assess the effect of the different U-values and thus age and construction materials on typical UK dwellings, floor plans for each dwelling type were required. Publicly available floor plans were obtained from [14]. The layouts adopted to develop the thermal energy demand database are shown in Fig. 4. Using the provided dimensions on the floor plans, along with reference images, baseline three-dimensional (3-D) models of each type of dwelling were created in IES VE using the Model Builder tool. Fig. 5 shows illustrative examples of the built models. From these models, relevant geometric properties were extracted and are presented in Table 2.

IES VE was adopted as a commercially licensed building simulation software which complies with multiple worldwide standards such as ASHRAE 140, CIBSE TM33 and ISO 150 [15]. Due to these attributes the software is used widely within the construction industry. Section 3 in the paper provides a modelling verification exercise to provide confidence on the adoption of IES VE to develop the thermal energy demand database.

2.4. Building orientation

Building orientation is an important attribute as it may affect energy consumption, indoor thermal comfort and use of lighting during daytime. It may also influence exposure to solar radiation: for instance, a south-facing orientation in Northern hemisphere countries like the UK will maximise the effect of winter sun, but will have an opposite effect during summer and thus increase cooling demand during warmer months. This is corroborated by BRE's guidance, which highlights the importance of building orientation in reducing overheating risk while allowing additional solar gains during winter to contribute to passive space heating [16].

To account for varying building orientations, four different orientations were considered to develop the thermal energy demand database: 0° (north), 90° (east), 180° (south) and 270°° (west). The north-facing direction was assigned to the top of each floor plan shown in Fig. 4 purely as a modelling convention. This enabled ensuring consistent rotation of the geometry within IES VE and had no effect on the simulation results. In addition to facilitating an easy adjustment of the global orientation of a dwelling, using this convention provides a clear reference for users of the database, allowing them to easily interpret orientation-dependent results.

Fig. 6 shows an example of the four building orientations for a detached house.

2.5. Geographical location

A key simulation parameter required to quantify thermal energy demand is the location of the dwelling. To identify relevant locations, the photovoltaic power potential in the UK was used, which is shown in Fig. 7.

As Fig. 7 illustrates, the solar intensity throughout the UK varies significantly, with cities in the South having more intense levels of solar irradiation compared to those in the North. Such an effect is more pronounced towards the Southeast. This needs to be accounted for within the modelling software as the solar heat gains can have a large impact upon the overall thermal energy demand in dwellings. To account for a wide range of solar intensity values, the following 6 geographical locations were selected: Plymouth, London, Cardiff, Manchester, Newcastle and Glasgow. To obtain the weather data for the selected locations, typical meteorological year (TMY) files were sourced from [17].

Fig. 4. *Dwelling floor plans for the most representative UK dwelling types* [14]*: (a) Bungalow; (b) detached house.*
Fig. 4 *(continued): Dwelling floor plans for the most representative UK dwelling types* [14]*: (c) flat; (d) semi-detached house; (e) terraced house.*

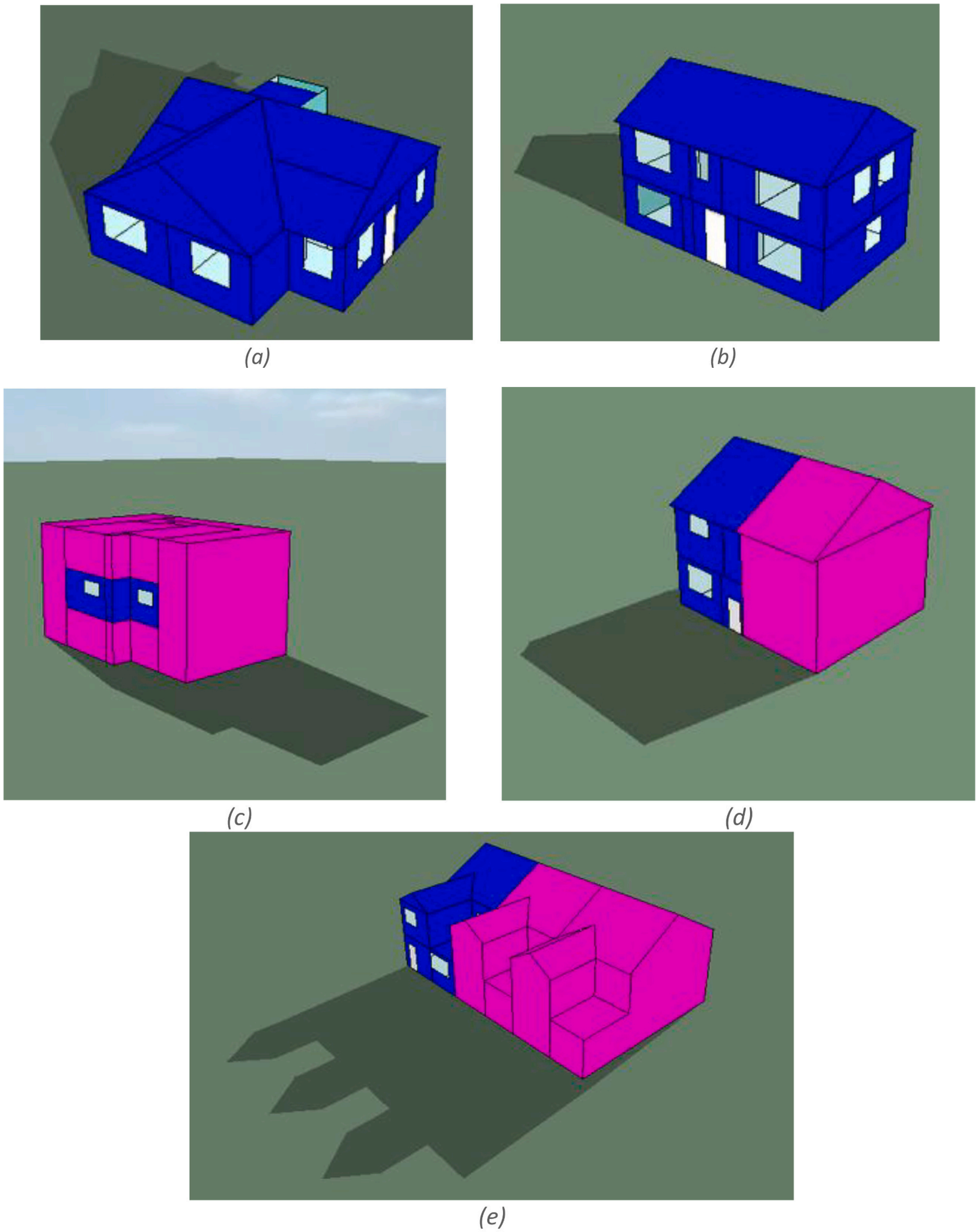


Fig. 5. Fig. 5 Examples of the most representative UK dwelling types built in IES VE: (a) Bungalow; (b) detached house; (c) flat; (d) semi-detached house; (e) terraced house.

To justify the selection of geographical locations further, historical average annual temperature distributions across the UK were examined. These are provided in Fig. 8. London and Plymouth exhibit the highest average temperatures among the chosen cities, reflecting the warmer conditions typically experienced in the South. Cardiff and Manchester fall within the mid-range of national temperatures and therefore represent more moderate climatic conditions. Newcastle lies within the transitional temperature range between the warmer southern cities and Glasgow, which exhibits lower average annual temperatures and is in turn representative of cooler northern climates. Although more extreme low-temperature regions exist further north of Glasgow and Edinburgh, these areas are sparsely populated and therefore less relevant for a national thermal energy demand assessment.

Together, the selected 6 geographical locations encompass a broad and representative range of both solar intensity and average annual temperature conditions across the UK.

2.6. *Differentiating between different dwelling constructions*

To build a comprehensive thermal energy demand database, it was

Table 2
Dwelling properties.

	Bungalow	Detached	Flat	Semi	Terraced
Floor area (m^2)	158.48	91.77	50.96	57.36	86.96
Volume (m^3)	252.82	192.72	123.34	137.68	191.32
External wall area (m^2)	98.51	117.52	38.50	72.91	89.1
External window area (m^2)	8.54	20.1	2.24	9.73	10.65

necessary to differentiate between the different dwelling constructions. Obsolete U-values were removed from this exercise, as single glazed windows have been banned since 2002 and roof insulation is both easy to install and has had multiple UK Government grants provided throughout the years. Each construction was given a unique dwelling code determined by the specific U-value used for each surface. This information is summarised in Table 3.

The most efficient dwelling within Table 3 (see top entries), with U-values of $0.18\,\mathrm{W}/(\mathrm{m}^2{\cdot}\mathrm{K})$ for walls, $0.13\,\mathrm{W}/(\mathrm{m}^2{\cdot}\mathrm{K})$ for foundations, $0.11\,\mathrm{W}/(\mathrm{m}^2{\cdot}\mathrm{K})$ for roofs and $1.2\,\mathrm{W}/(\mathrm{m}^2{\cdot}\mathrm{K})$ for windows would be assigned a dwelling code '1111'. Changing the type of windows would only affect the fourth digit in the code. For instance, a building code '1114' would refer to the most thermally efficient dwelling with respect to its walls, foundation and roof but with the least efficient type of windows ($3.1\,\mathrm{W}/(\mathrm{m}^2{\cdot}\mathrm{K})$). A less thermally efficient dwelling would thus have a dwelling code with entries towards the bottom of the table for each building component; i.e. code '7654' would be used for the least thermally efficient home.

2.7. Incorporating internal heat gains

The baseline models do not include heat gains generated from internal sources such as people, equipment or lighting. These heat gains can be considered post-modelling by adding the loads to the generated data. This section details sample load profiles extracted from CIBSE TM59 and example custom-made profiles. Users may create additional profiles using the methodology described next.

2.7.1. CIBSE TM59

CIBSE TM59 provides a comprehensive occupancy schedule and loads for overheating risk assessments. The guide is aimed towards flats; however, the methodology applies to houses as well. Fig. 9 shows the internal load profiles generated from CIBSE TM59 [20].

Table 4 shows the differences in internal gains between the differing dwellings considering CIBSE TM59 loads, which complements the information presented in Fig. 9.

As shown in Fig. 9 and Table 4, the internal gains differ between dwelling types due to differences in assumed occupancy and floor area (see Table 2). For the bungalow, detached and terraced houses, identical occupancy values were used because these typologies were assigned the same number of bedrooms within the modelling framework. This consideration results in an effective occupancy of approximately 4 people per dwelling. Flats, being smaller and having only one bedroom, have correspondingly lower occupant gains and reduced equipment loads, equivalent to approximately 2 people per dwelling. The semi-

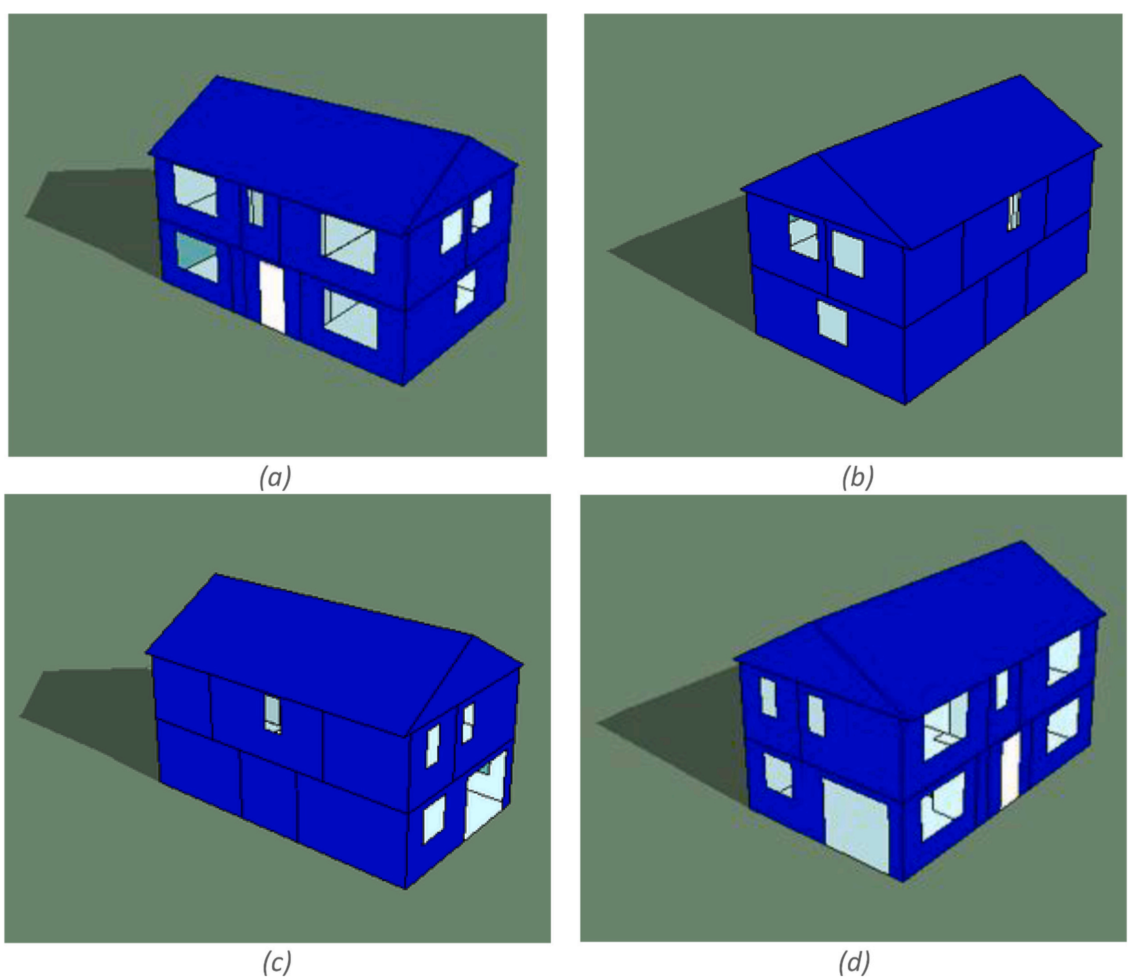


Fig. 6. Effect of building orientation for a detached house: (a) 0° (north); (b) 90° (east); (c) 180° (south); (d) 270° (west).

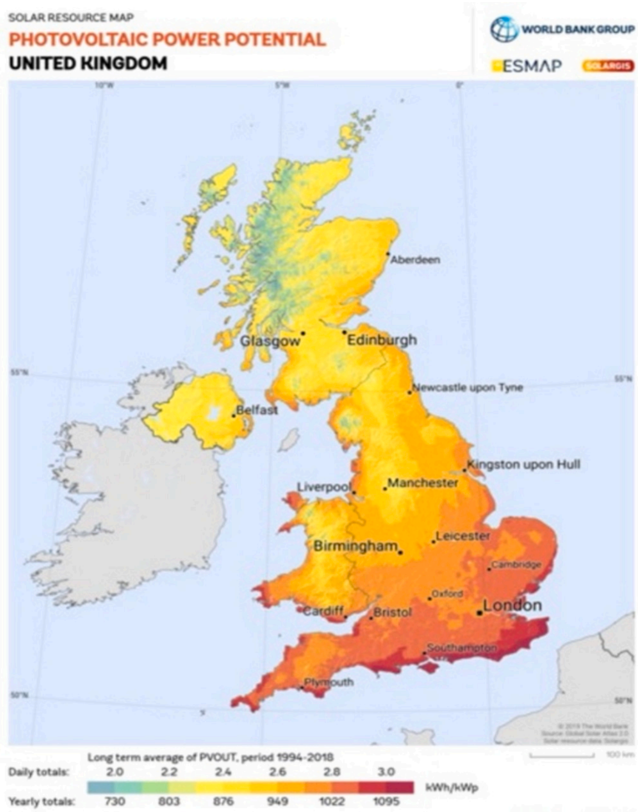


Fig. 7. Photovoltaic power potential in the UK [18].

detached dwelling, comprising two bedrooms, was assigned an effective occupancy of three people. The equipment and lighting loads for each dwelling type follow the standard values and schedules defined in CIBSE TM59, scaled where necessary according to dwelling size.

While providing a useful metric to assess the overheating risk in the summer, the load profiles generated have some drawbacks. These were created assuming the dwellings are always occupied. The loads also do not account for variations in occupancy schedules during the weekends. Lighting loads times vary throughout the year due to differing sunset/sunrise times: 18:00 is a conservative time for the UK and during winter lights will be on in the mornings.

The lighting load was considered as $2\ \mathrm{W/m^2}$ as per CIBSE TM59 (matching with light emitting diodes -LEDs-). However, this value may be adjusted based on the type of lighting installed within the dwelling. This is further discussed in Section 2.7.2.

2.7.2. Custom loads

CIBSE Guide A does not cover residential properties. However, the standard provides equipment loads found in commercial properties that are also used in dwellings (such as televisions and computers) [13]. Therefore, heat gains for typical equipment used in residential properties can be derived from the guide.

The nominal lighting load of $2\ \mathrm{W/m^2}$ according to CIBSE TM59 discussed in Section 2.7.1 may be adjusted based on the type of lighting installed within the dwelling. Assuming LED lights have an efficacy of approximately 120 Lum/W, heat gains Q_L for older lighting installed in dwellings can be calculated with:

$$Q_L = \frac{K_{LED}}{K_i} \times q_i \tag{1}$$

where K_{LED} is the efficacy of LED lights (Lum/W), K_i is the efficacy of the lights installed within the dwelling (Lum/W) and q_i is the lighting load density ($\mathrm{W/m^2}$). For example, using halogen lights which have an efficacy of 20 Lum/W,

$$Q_L = \frac{120}{20} \times 2 = 12\ \mathrm{W}\Big/\mathrm{m}^2 \tag{2}$$

Eq. (1) allows adjusting the lighting load to better simulate the heat gains from lights.

The Office for National Statistics provides information on the amount of time people in the UK spend doing various activities [21]. Fig. 10 presents the time spent on an average day for weekends and weekdays as a stacked area chart.

Using the national time-use behavioural patterns in Fig. 10 along

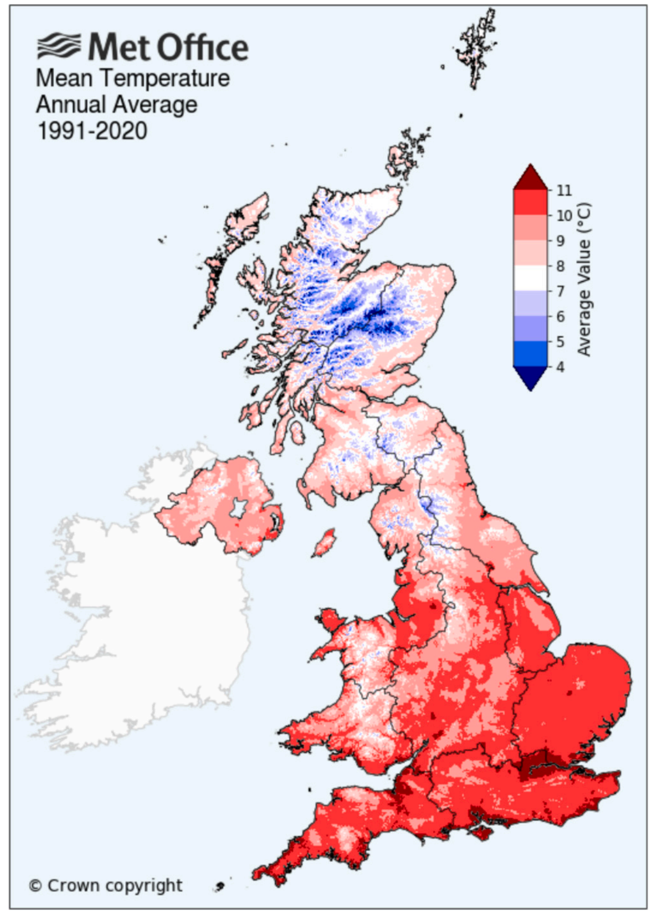


Fig. 8. Mean temperatures in the UK [19].

Table 3
Assigning U-values to each type of dwelling construction via building codes [1].

Building code digit		*U-values* $[\mathrm{W/(m^2{\cdot}K)}]$			
		Walls	*Foundations*	*Roofs*	*Windows*
Most efficient	***1***	0.18	0.13	0.11	1.2
	2	0.3	0.22	0.13	1.4
	3	0.45	0.51	0.22	2
	4	0.6	1.2	0.35	3.1
	5	1	2.94	0.4	–
	6	1.7	3.25	–	–
Least efficient	***7***	1.84	–	–	–

[1] The building code is a four digit number encapsulating the U-values of key construction data within the building envelope of a dwelling. It has a structure 'WXYZ', where W represents the digit for the U-value of walls, X for foundations, Y for roofs and Z for windows. Entries for walls range from 1 to 7, for foundations from 1 to 6, for roofs from 1 to 5 and for windows from 1 to 4. The lowest digit for each entry represents the most thermally efficient material and the highest digit the least thermally efficient material.

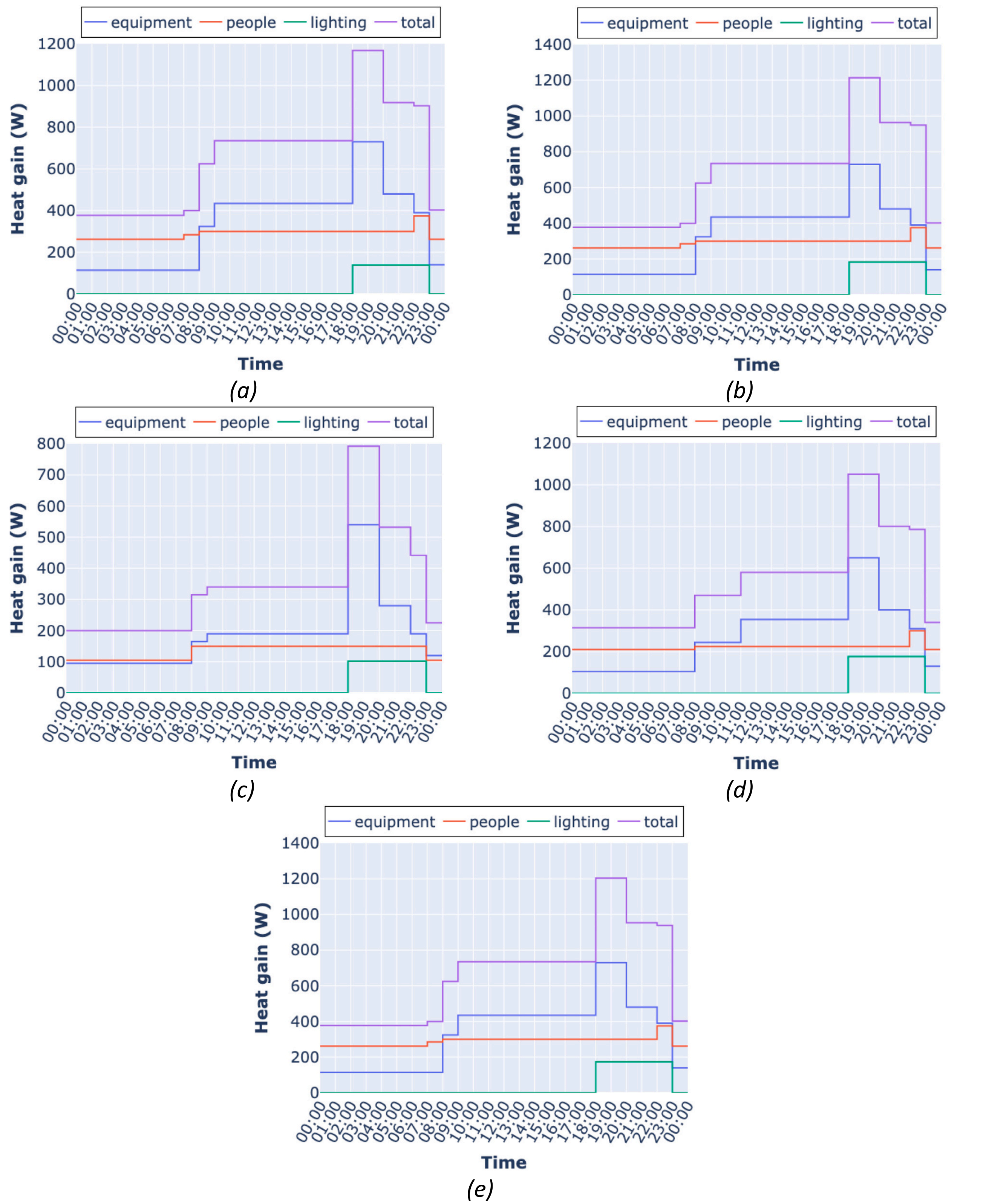


Fig. 9. Daily internal load profiles generated following CIBSE TM59 for: (a) bungalow; (b) detached house; (c) flat; (d) semi-detached house; (e) terraced house.

with equipment loads taken from CIBSE Guide A and the lighting and people loads extracted from CIBSE TM59 (summarised by Table 4 and Fig. 9), internal gain profiles were created to produce representative weekday and weekend load profiles. The following additional assumptions were made:

- Every resident owns a laptop.
- There is always one person at home.
- The additional bedrooms contain children who are at school during school hours.

Table 4
Internal load profiles (in W) for each dwelling.[1]

Time	Bungalow			Detached			Flat			Semi-detached			Terraced		
	E	L	P	E	L	P	E	L	P	E	L	P	E	L	P
01:00	115	0	262.5	115	0	262.5	95	0	105	105	0	210	115	0	262.5
02:00	115	0	262.5	115	0	262.5	95	0	105	105	0	210	115	0	262.5
03:00	115	0	262.5	115	0	262.5	95	0	105	105	0	210	115	0	262.5
04:00	115	0	262.5	115	0	262.5	95	0	105	105	0	210	115	0	262.5
05:00	115	0	262.5	115	0	262.5	95	0	105	105	0	210	115	0	262.5
06:00	115	0	262.5	115	0	262.5	95	0	105	105	0	210	115	0	262.5
07:00	115	0	285	115	0	285	95	0	105	105	0	210	115	0	285
08:00	325	0	300	325	0	300	165	0	150	245	0	225	325	0	300
09:00	435	0	300	435	0	300	190	0	150	245	0	225	435	0	300
10:00	435	0	300	435	0	300	190	0	150	245	0	225	435	0	300
11:00	435	0	300	435	0	300	190	0	150	355	0	225	435	0	300
12:00	435	0	300	435	0	300	190	0	150	355	0	225	435	0	300
13:00	435	0	300	435	0	300	190	0	150	355	0	225	435	0	300
14:00	435	0	300	435	0	300	190	0	150	355	0	225	435	0	300
15:00	435	0	300	435	0	300	190	0	150	355	0	225	435	0	300
16:00	435	0	300	435	0	300	190	0	150	355	0	225	435	0	300
17:00	435	0	300	435	0	300	190	0	150	355	0	225	435	0	300
18:00	730	138	300	730	184	300	540	102	150	650	176	225	730	174	300
19:00	730	138	300	730	184	300	540	102	150	650	176	225	730	174	300
20:00	480	138	300	480	184	300	280	102	150	400	176	225	480	174	300
21:00	480	138	300	480	184	300	280	102	150	400	176	225	480	174	300
22:00	390	138	375	390	184	375	190	102	150	310	176	300	390	174	375
23:00	140	0	262.5	140	0	262.5	120	0	105	130	0	210	140	0	262.5
24:00	140	0	262.5	140	0	262.5	120	0	105	130	0	210	140	0	262.5

[1] 'E' stands for equipment loads, 'L' stands for lighting loads and 'P' stands for occupancy (people) loads.

- Since CIBSE Guide A considers equipment loads using a reference from 2011, heat gains were updated to reflect more modern technology (e.g. lower power densities).

The occupancy schedules created for each of the dwellings are presented in Fig. 11 for weekdays and Fig. 12 for weekends. From Fig. 10 it can be observed that, on weekdays, a large proportion of adults leave their homes at approximately 08:00 and return between 15:00 and 18:00. Accordingly, full occupancy was applied between 00:00–08:00 and 18:00–24:00, with a short increase in daytime activity around 12:00–14:00 to represent lunchtime returns. This period, together with the evening arrival around 18:00, was also used to assign higher equipment loads associated with meal preparation. For weekends, the time-use data indicate that occupants spend most of the day at home, resulting in higher and more consistent occupancy and equipment use across the day.

It is worth noting that lighting loads are originally set for the summer months. Consequently, additional loads should be applied in the morning between 06:00 and 08:00 for the winter months due to the later sunrise times. As mentioned earlier in this section, the lighting load may be also adjusted for less efficient lighting using (1).

2.8. Conducting IES VE simulations

With the available data presented in the previous sections, simulations using IES VE were run for each variation of constructions, dwelling types, locations and orientations to calculate the thermal energy demand. Each dataset corresponds to an individual simulation rather than an entry from a pre-existing database. In total, this required the execution of a large number of simulations to populate the complete database.

The thermal energy demand was assumed as the thermal energy required to maintain an indoors set-point temperature of 21°C in the dwelling. At each simulation timestep, IES VE solves a transient heat balance for the building. In simplified form, the thermal energy demand $\dot{Q}_{dem}$ is expressed as:

$$\dot{Q}_{dem} = \dot{Q}_{fab} + \dot{Q}_{vent} + \dot{Q}_{inf} - \dot{Q}_{int} - \dot{Q}_{sol} \quad (3)$$

where $\dot{Q}_{fab}$ accounts for fabric heat transfer, $\dot{Q}_{vent}$ for ventilation losses, $\dot{Q}_{inf}$ for infiltration losses, $\dot{Q}_{int}$ for internal heat gains and $\dot{Q}_{sol}$ for solar gains [22]. In (3), positive values of $\dot{Q}_{dem}$ represent heating demand and negative values represent cooling demand. The resulting demand constitutes the thermal energy required to maintain the prescribed indoor temperature and is independent of any specific heating or cooling system.

As noted in [8], the chosen value of set-point temperature aligns with CIBSE Guide A, which recommends indoor air temperatures of 21°C to 25°C depending on the room type [13]. Additionally, CIBSE TM59 outlines preventative measures, such as opening windows, to mitigate overheating when indoor temperatures exceed thresholds like 22°C [18]. The thermal energy demand quantification adopted for the production of the datasets does not consider any heat or cooling source to maintain such a temperature.

Infiltration in all dwellings was modelled using a fixed air change rate to prevent the need for repeated simulations with varying ventilation rates. Such an approach includes background air leakage, but no other air leakage pathways were accounted. A value of 0.4 air changes per hour (ACH) was applied consistently across the dataset as this provided the best agreement with measured data during the modelling verification process presented in Section 3. The interested readers are referred to [8] for a more detailed explanation on the choice of air change rates. This modelling simplification alongside other assumptions and limitations of the methodology to build the thermal energy demand database are further discussed in Section 7.

3. Verification of the adopted modelling approach to build the database

This section summarises the verification exercise presented in [8] to provide confidence on the methodology and building modelling software adopted in this paper to create the thermal energy demand database. The example reported in this section is thus not part of the database. For a comprehensive description of the modelling verification method, the interested readers are referred to [8].

As a commercially licensed software, IES VE has been validated against various worldwide standards such as ASHRAE 140, CIBSE TM33 and ISO 5200 [15]. However, further verification was carried out to

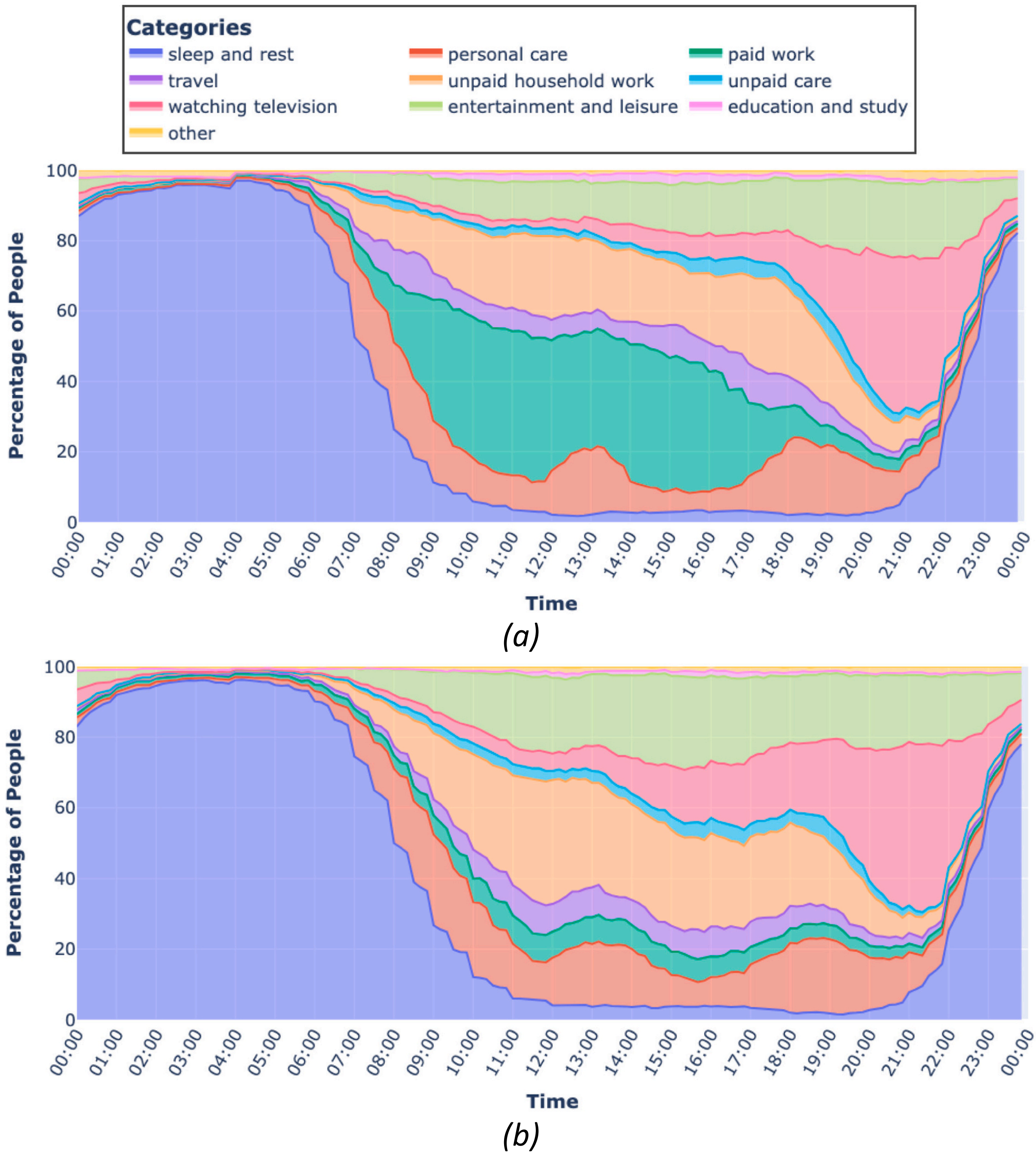


Fig. 10. Percentage of adults doing specified activities at specified times during an average (a) weekday and (b) weekend day (UK, March 2023) [21].

provide confidence in the modelling methodology adopted to produce the datasets discussed in Section 2. Information retrieved from [23] was used to generate an IES VE simulation model of two semi-detached houses as shown in Fig. 13.

As per [23], internal temperatures within the dwellings were monitored with the control house (on the right-hand side in Fig. 13) keeping windows closed at all times alongside simulated internal heat gains using heaters installed in each room. Using IES VE the control house was simulated and the internal air temperatures from each room were compared to the measured data. A sample output showing the comparison between simulated and measured temperatures is provided in Fig. 14.

To compare the experimental data provided in [23] with the simulation results using IES VE, three accuracy metrics were adopted. The mean absolute error (MAE), root mean squared error (RMSE) and the coefficient of determination (R^2) were used to quantify the agreement between the measured and simulated values. These accuracy metrics are defined as follows [24]:

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|S_i - M_i| \tag{4}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(S_i - M_i)^2} \tag{5}$$

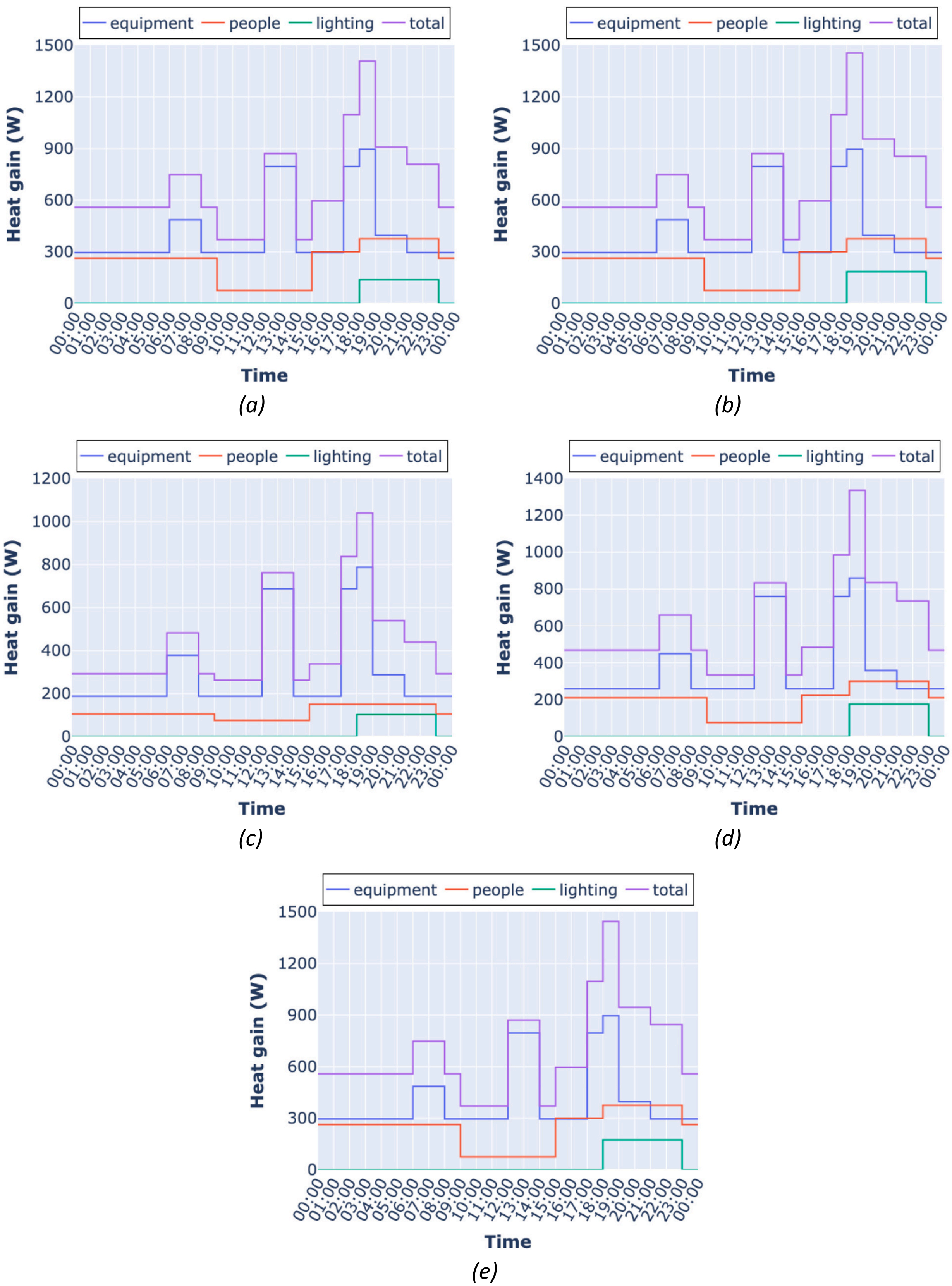


Fig. 11. Custom daily internal load profiles on a weekday for: (a) bungalow; (b) detached house; (c) flat; (d) semi-detached house; (e) terraced house.

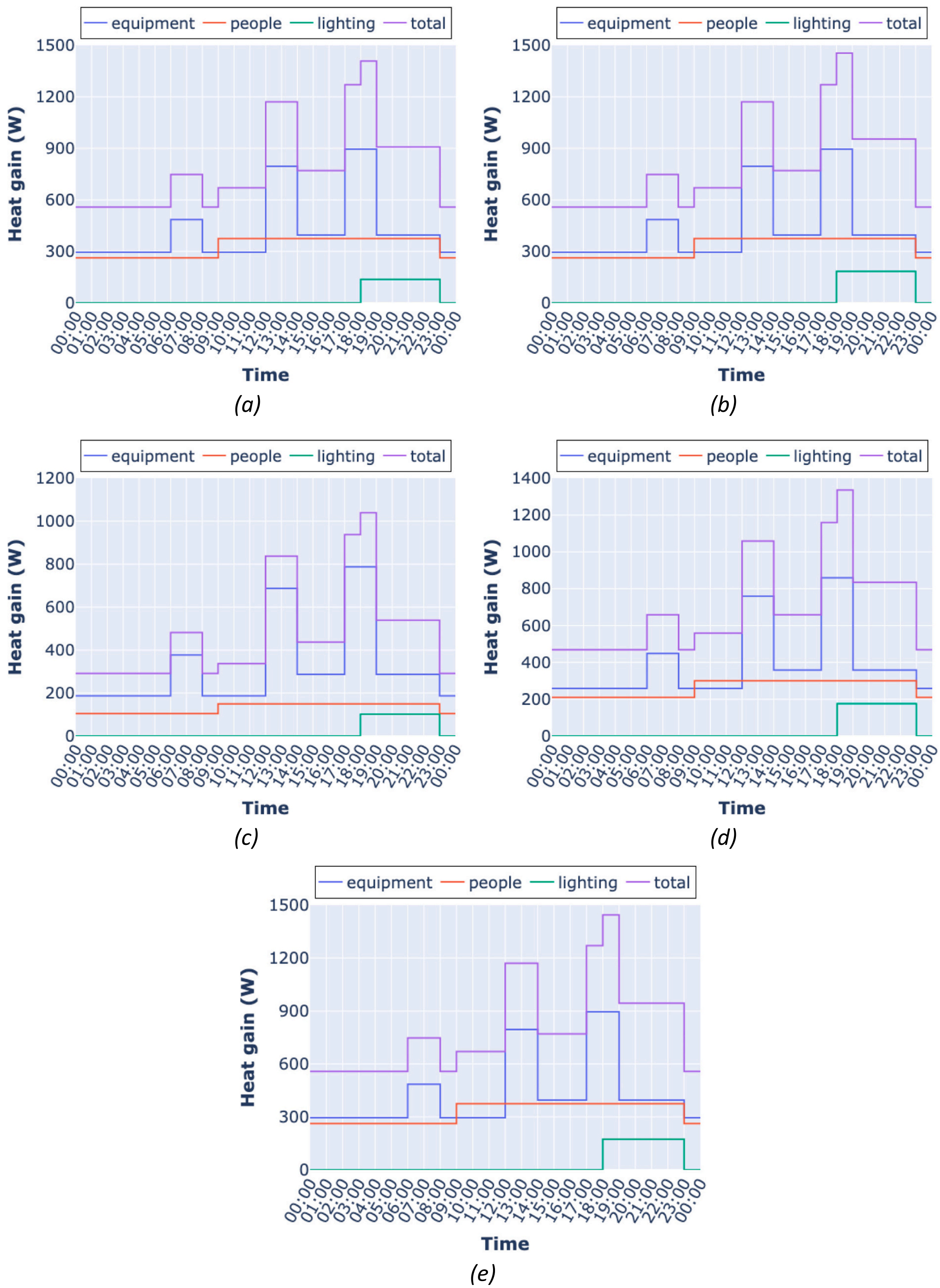


Fig. 12. Custom daily internal load profiles on a weekend day for: (a) bungalow; (b) detached house; (c) flat; (d) semi-detached house; (e) terraced house.

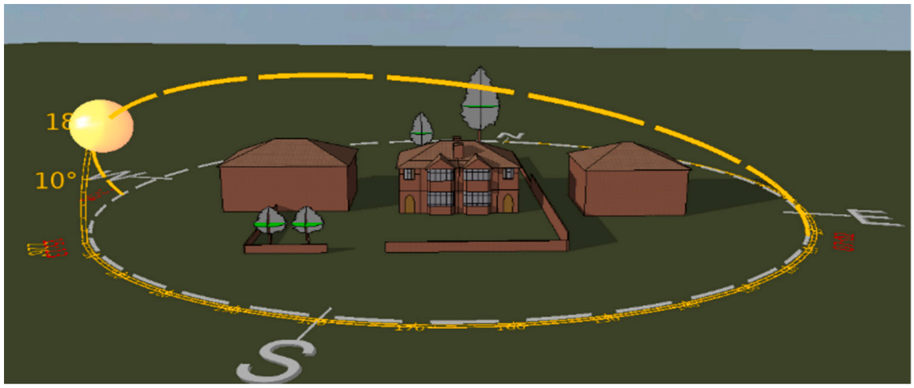


Fig. 13. Houses from [23] modelled using IES VE.

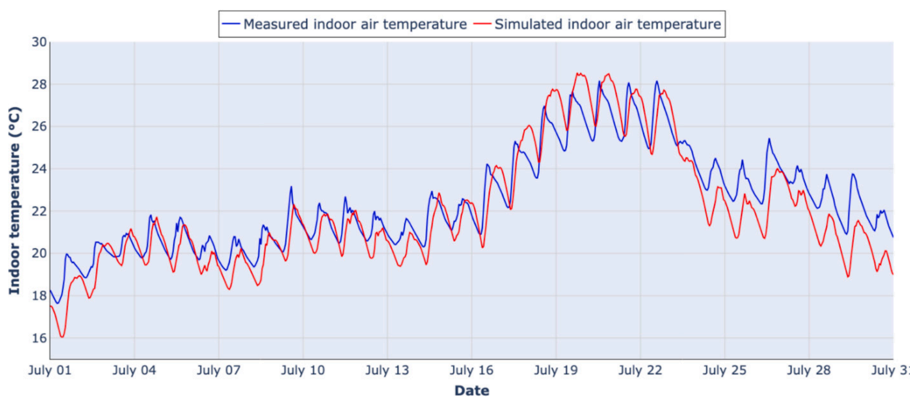


Fig. 14. Comparison of the internal room temperature in the living room using IES VE and the measured values reported in [23].

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (M_i - S_i)^2}{\sum_{i=1}^{n} (M_i - \overline{M})^2} \tag{6}$$

where S_i and M_i denote the simulated and measured values at timestep i, $\overline{M}$ is the mean of the measured values and n is the total number of datapoints.

A summary of the comparison is shown in Table 5. The obtained metrics provide confidence on the adopted modelling approach to build the thermal energy demand database.

For a more detailed description of the verification method used, the interested readers are referred to [8].

4. Data records

All the data accompanying this paper are available to download from the following online repository: 10.17035/cardiff.30305833. These data are provided in 4 datasets with information saved in CSV format:

Table 5
Accuracy metrics for the simulated and measured data.

	Living room	Kitchen	Front bedroom	Rear bedroom	Single bedroom
R^2	0.87	0.84	0.90	0.91	0.85
MAE (°C)	1.68	1.99	1.10	0.73	1.22
RMSE (°C)	2.01	2.37	1.32	0.90	1.49

1. **Thermal energy demand,** comprised of the total thermal energy required to maintain a set-point temperature of 21°C in the dwelling.
2. **Solar gains,** which contains the heat gains associated with the solar gains entering the dwelling.
3. **Conduction gains,** containing the heat gains entering the dwelling via conduction through the external surfaces.
4. **Infiltration gains,** containing the heat gains and losses due to infiltration into the dwelling.

The weather files obtained from [17] are also made available in a separate folder (see Section 5 for further information).

The thermal energy demand dataset provides hourly heating and cooling demand within a dwelling for the TMY. The profile for the TMY is directly available to download from [17]. Positive values constitute heating demand and negative values represent cooling demand. A date time index has been applied to each of the CSV files. Although no specific year for thermal energy demand quantification has been indicated as the simulations were conducted using TMY weather files, year 2001, a non-leap year (with 8760 h) was selected to aid in the creation of data frames.

In the following figures, graphs exemplifying the aforementioned datasets are provided. These have been plotted for a detached house in Cardiff. A highly thermally efficient dwelling with a building code '1111' as indicated in Table 3 and orientated at 0° (north-facing) has been considered.

Fig. 15 provides the hourly thermal energy demand to maintain an indoor temperature of 21°C. As expected, there is heating demand in winter (positive values) and cooling demand during summer (negative values). While this demand quantification has been made to account for an indoors set-point temperature of 21°C, it is possible to adjust the thermostat settings in the dwelling to consider a different temperature.

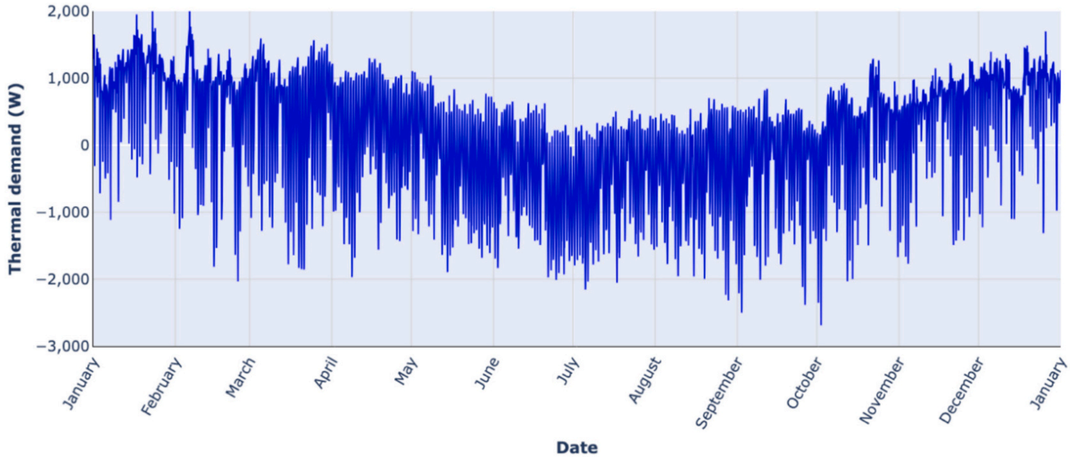


Fig. 15. Example of hourly thermal energy demand for the TMY. Dataset for a north-facing (orientated at 0°), highly thermally efficient detached house in Cardiff (building code '1111').

Such methodology is later described in Section 5.2.

Fig. 16 shows the hourly heat gains due to the direct solar gains entering the dwelling through the windows.

Fig. 17 shows the hourly heat gains from the conduction of heat through the external surfaces (e.g. windows, walls, roof, floor). These gains can be either negative or positive depending upon the outdoor air temperature. This is because heat will always flow from a region of higher temperature to one of a lower temperature. With a set internal temperature of 21°C, when the external surface temperature is lower, heat will exit the dwelling and when the external surface temperature is higher, it will enter it.

Fig. 18 shows the hourly infiltration gains for each dwelling. Similar to the conduction gains shown in Fig. 17, infiltration gains can be either positive or negative. This is because these gains represent the direct transfer of air between the internal rooms and the outdoor air temperature. When the outdoor air temperature is greater than the indoor air temperature, the infiltration gains are positive.

5. Database usage notes

The generated database consists of approximately 220,000 individual datasets, each representing a single year of data at hourly timesteps. Each CSV file contains 840 datasets corresponding to unique dwelling thermal efficiencies. The files are organised by 11 dwelling types, including variations by flat location and position within a building, 6 geographical locations and 4 orientations for each dwelling.

5.1. Accessing data

The following sections provide instructions on how to find the relevant data and obtain the desired results from the dataset.

5.1.1. Directory layout

Information on the layout of the directory structure and how to access the relevant CSV file is provided in Table 6.

A list of all folder parameters is provided in Table 7.

Use of Tables 6 and 7 leads to the CSV files for a specific dwelling type, location and orientation. This CSV file will contain the desired simulation results for all possible combinations of construction U-values.

5.1.2. Dataset layout

Each CSV file contains the results for every dwelling code and the outputs of the simulations for each one was saved using the format shown in Table 8. To extract the desired results, the dwelling code can be used to search for the relevant column in the CSV file.

For flats, some surfaces are not used depending on their position within the building. For example:

- Ground floor flats do not have an exposed roof.
- Mid floor flats have neither an exposed roof nor exposed foundations.

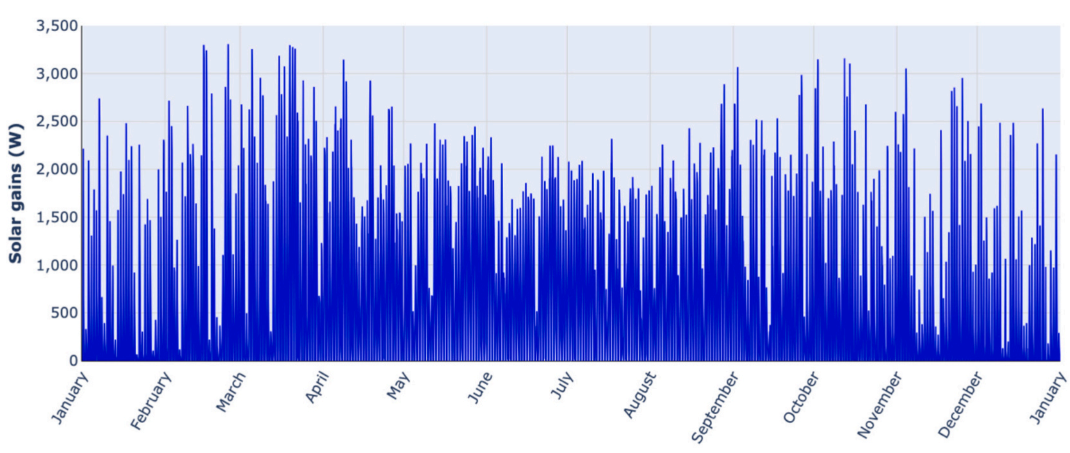


Fig. 16. Example of hourly heating gains from solar radiation in a north-facing (orientated at 0°) highly thermally efficient detached house in Cardiff (building code '1111').

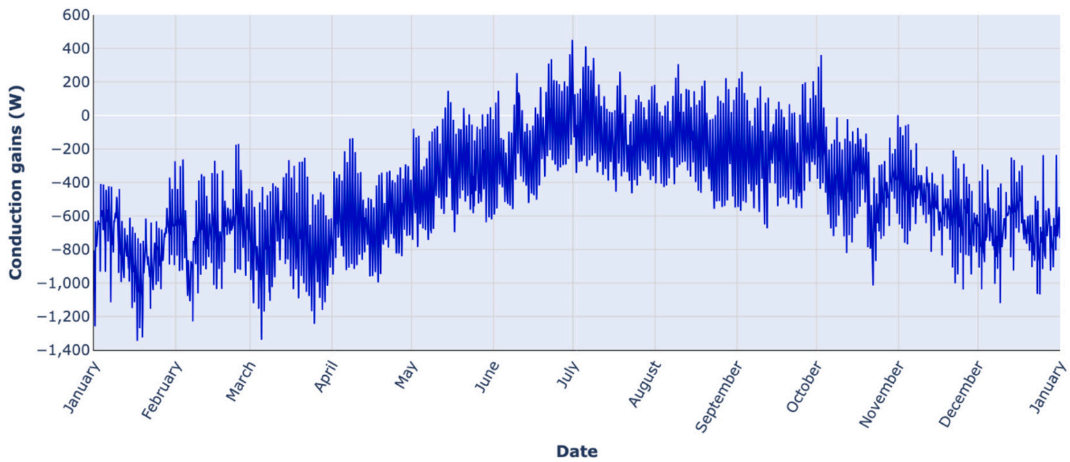


Fig. 17. Example of hourly conduction gains for a north-facing (orientated at 0°) highly thermally efficient detached house in Cardiff (building code ‘1111’).

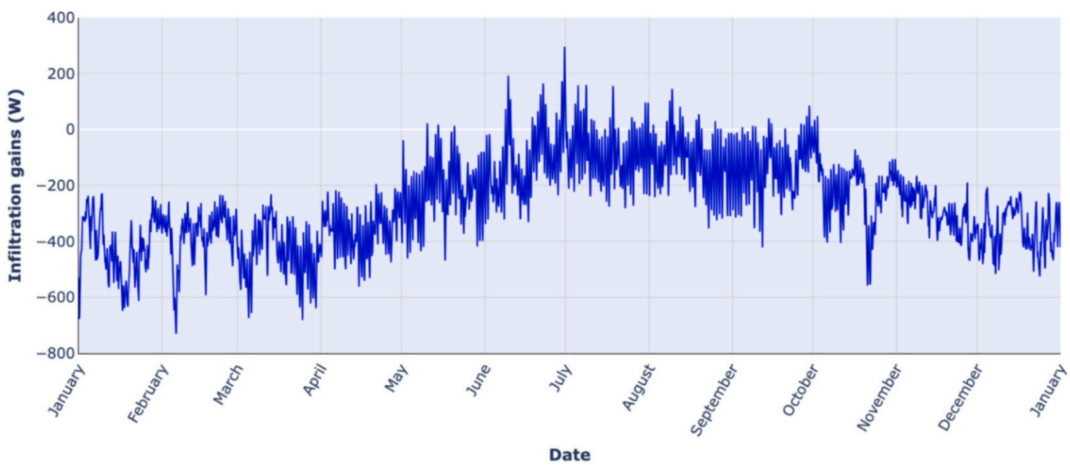


Fig. 18. Example of hourly infiltration gains for a north-facing (orientated at 0°) highly thermally efficient detached house in Cardiff (building code ‘1111’).

Table 6
Directory structure for simulated data files.

Directory	Description
‘root/’	The main directory containing all files.
‘root/{dwelling_type}/’	Contains subdirectories specific to each dwelling type. Replace {dwelling_type} with dwelling types, e.g., ‘Bungalow’, ‘Detached’, ‘Terraced (mid)’.
‘root/{dwelling_type}/{location}/’	Contains subdirectories specific to each location. Replace {location} with the desired location e.g., ‘Cardiff’, ‘London’, ‘Plymouth’, ‘Newcastle'.
‘root/{dwelling_type}/{location}/{orientation}/’	Contains data and subdirectories specific to each orientation. Replace {orientation} with the desired building orientation e.g., ‘0’, ‘90’, ‘180’.
‘root/{dwelling_type}/{location}/{orientation}/{data_type}’	Allows access to the csv files containing the simulated results for each construction type, specific to dwelling, location, and orientation. Replace {data_type} with the desired data type e.g., ‘Thermal demand.csv’, ‘Window solar gains.csv’, ‘Infiltration gains.csv’.

- Top floor flats have no exposed foundations.

In cases such as ground floor flats (no exposed roof), mid-floor flats (no exposed roof or floor) and top-floor flats (no exposed floor), the respective U-values are excluded from the load calculations. To maintain

Table 7
Folder parameters.

Directory	Description
Dwelling type	‘Bottom Flat’, ‘Bottom Flat (corner)’, ‘Bungalow’, ‘Detached’, ‘Mid Flat’, ‘Mid Flat (corner)’, ‘Semi’, ‘Terraced (end)’, ‘Terraced (mid)’, ‘Top Flat’, ‘Top Flat (corner)’
Location	‘Cardiff’, ‘Glasgow’, ‘London’, ‘Manchester’, ‘Plymouth’, ‘Newcastle'
Orientation	‘0’, ‘90’, ‘180’, ‘270’
Data type	‘Conduction gains from ext surfaces’, ‘Infiltration gains’, ‘Thermal demand’, ‘Window solar gains’

Table 8
Dataset layouts.

	1111	1112	…	7653	7654
2001-01-01 00:00:00[1]	…[2]	…	…	…	…
2001-01-01 01:00:00	…	…	…	…	…
…	…	…	…	…	…
2001-12-31 22:00:00	…	…	…	…	…
2001-12-31 23:00:00	…	…	…	…	…

[1] Year 2001 was used simply for reference. The calculated results are for an average year based on the TMY weather files.
[2] These represent the hourly heat gains in Watts for each of the dwelling codes.

consistency across all CSV files, dwelling codes remained the same by replicating results from the base model. For instance, the results for dwellings with building codes ‘1111’, ‘1121’, ‘1131’, ‘1141’ and ‘1151’ share the same data in the ground floor flats.

5.2. Adjusting temperature set-points

An indoor temperature set-point for thermal comfort can vary across different dwellings depending on occupants' preferences and guidelines prescribed by regional regulatory authorities. For example, in the UK, CIBSE Guide A recommends that the internal room temperatures should be set between 21°C to 25°C depending upon the type of room [13]. Whereas, in warmer climate countries such as the UAE, the recommended indoor temperature should be set as 24°C ± 1.5°C [25]. To understand the effects of varying indoor air temperature on dwellings, a typical detached house with a dwelling code ‘3244’ in Cardiff with an orientation of 0° was simulated with 4 different temperature set-points. For clarity, a weeks' worth of the results are shown in Fig. 19.

As shown in the figure, adjusting the temperature set-points has a constant effect on the thermal demand of the dwelling. In this scenario, raising the temperature by 1°C increases the thermal demand by approximately 160 W. These results are scalable; that is, increasing the temperature by 0.1°C would require an addition of approximately 16 W to the thermal demand.

To avoid conducting new simulations for each dwelling at different set-point temperatures, a methodology was developed to estimate the energy requirements due to adjustments of such temperature with respect to a baseline set-point of 21°C. The interested readers are referred to [8], where this information is presented in detail.

Table 9 shows the surface weightings used to adjust the thermostat setting for any type of dwelling as defined in [8]. These weightings were obtained by initially assigning unknown values to each surface U-value and calculating the correlation coefficient between the total weighted U-value (i.e. the sum of all U-values multiplied by their respective weightings) and the resulting change in energy demand due to a 1°C change in set-point temperature. Particle swarm optimisation was then applied to heuristically adjust the weightings until the correlation coefficient approached 1, producing a linear relationship between the weighted U-value and the energy change.

Table 9 also shows the change in thermal energy required to adjust the set-point temperature in a dwelling by 1°C, given as a linear equation. In the equation, x is the weighted total U-value of a dwelling calculated by multiplying each of the surface U-values in Table 3 with their individual weightings in Table 9 and then summated. An example calculation for a detached house with dwelling code ‘1111’ is provided next:

Table 9
Simplified equations to modify internal set-point temperatures.

Dwelling	Surface weightings				Equation
	Wall	**Ground**	**Roof**	**Window**	
Bottom flat	18.97	55.66	–	7.88	$y = 0.97x + 5.57$
Bottom flat (corner)	35.46	54.82	–	8.02	$y = 0.97x + 6.67$
Bungalow	6.74	9.87	2.13	1.86	$y = 7.82x + 44.44$
Detached house	9.92	5.13	1.06	1.72	$y = 8.78 + 26.33$
Mid flat	22.68	–	–	7.84	$y = 0.68x + 14.07$
Mid flat (corner)	39.85	–	–	7.92	$y = 0.82x + 11.97$
Semi-detached house	9.35	4.57	4.28	0.91	$y = 7.12x + 30.86$
Terraced house (end)	9.87	6.47	2.28	1.06	$y = 7.71x + 44.57$
Terraced house (mid)	8.30	9.57	4.29	1.62	$y = 5.33x + 40.83$
Top flat	31.89	–	0.01	12.89	$y = 0.61x + 16.05$
Top flat (corner)	82.89	–	0.01	17.61	$y = 0.44x + 16.46$

$$x = (0.18 \times 9.92) + (0.13 \times 5.13) + (0.11 \times 1.06) + (1.2 \times 1.72) = 4.63\ \mathrm{W}/(\mathrm{m}^2{\cdot}\mathrm{K}) \tag{7}$$

To determine the change in thermal energy y for the detached house due to the change in set-point temperature, the corresponding equation from Table 9 is used, with $x = 4.63\ \mathrm{W}/(\mathrm{m}^2{\cdot}\mathrm{K})$:

$$y = (8.78 \times 4.63) + 26.33 = 67.01\ \mathrm{W} \tag{8}$$

Thus, to adjust the desired internal air temperature in a detached house with dwelling code ‘1111’ from 21°C to 22°C, 67.01 W should be added to every thermal energy demand value within the dataset. As previously mentioned, this result is scalable, so increasing the set-point temperature from 21°C to 23°C (i.e. by 2°C) would require an additional 134.02 W.

6. Representative results

To showcase relevant characteristics of the thermal energy demand database, this section shows examples of potential outputs which could be obtained.

The results presented represent an illustrative reduced sample of the outputs available from the database. They are included to showcase the type of information and insights that can be obtained, rather than to provide an exhaustive summary of all data contained within the database.

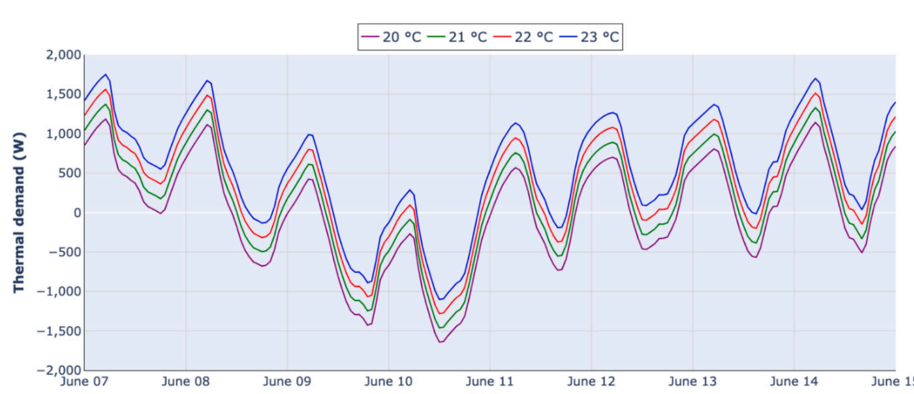


Fig. 19. Comparison of hourly thermal energy demand with different thermostat temperatures for a TMY. Detached house in Cardiff at orientation 0° (i.e. north-facing) with a building code ‘3244’. Figure reproduced from [8].

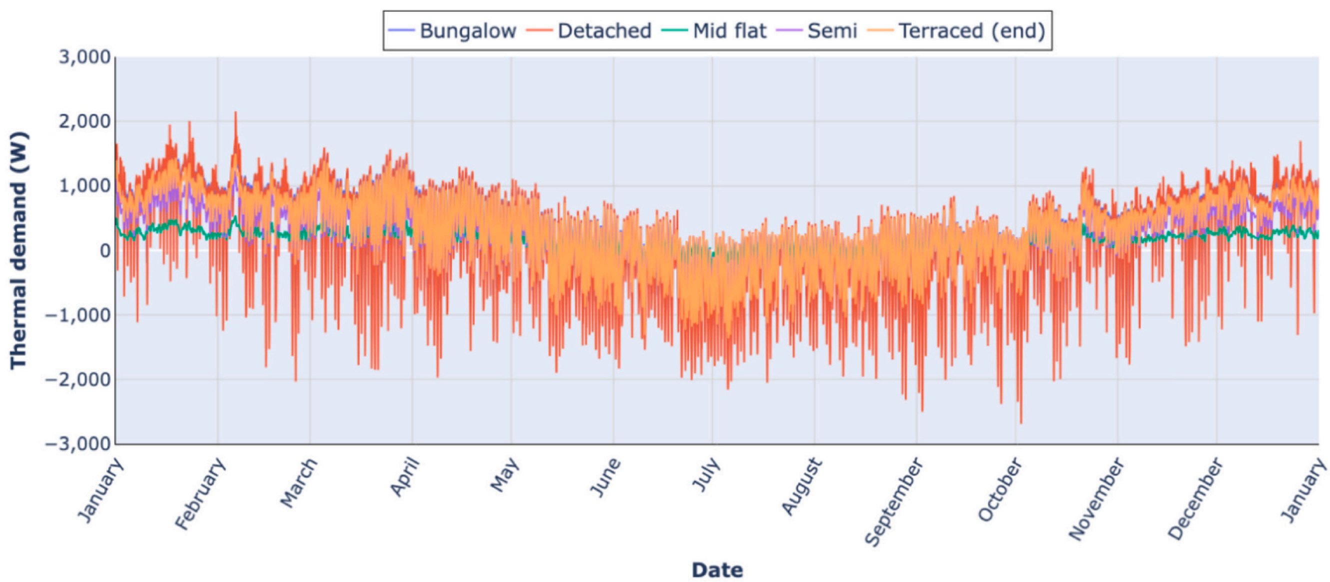
6.1. Annual thermal energy demand by dwelling type

The thermal energy demand of a dwelling varies significantly with its type. This is illustrated in Fig. 20 for high efficiency and low efficiency dwellings located in Cardiff. The detached house (red trace) exhibits the highest heating demand (positive values) and cooling demand (negative values) irrespective of the thermal efficiency of the building envelope because of its larger volume and greater external surface area. At the other end of the spectrum, the flat (green trace) shows the most steady thermal demand with the lowest heating and cooling requirements.

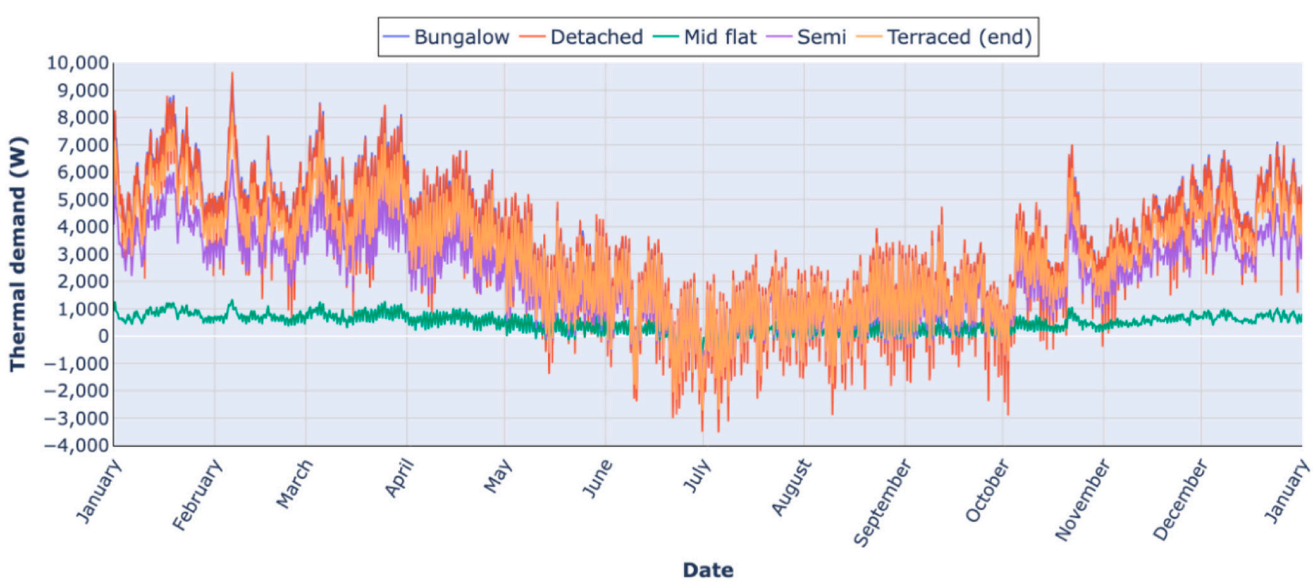
As shown in Fig. 20a, a dwelling with an improved thermal efficiency exhibits substantially reduced peak heating demand during winter, reflecting lower fabric heat losses and improved insulation performance. This reduction in heating demand dominates the annual thermal energy balance and remains the primary contributor to total energy demand. At the same time, improved thermal efficiency leads to a more persistent cooling demand throughout the year, as internally and externally generated heat is retained more effectively within the dwelling.

In contrast, Fig. 20b shows that dwellings with lower thermal efficiency experience significantly higher peak heating demand, particularly during cold winter periods, due to increased heat losses through the building envelope. Although these dwellings also experience higher peak cooling loads, such events are less frequent than in more thermally efficient dwellings, and heat demand remains the dominant component of annual thermal energy use.

In addition to the simulations for Cardiff, similar data can be extracted for other locations. An example is provided in Fig. 21, which presents the same dwelling types, orientations and dwelling codes for Newcastle. As shown in Fig. 21, the relative performance of thermal energy demand profiles is maintained across dwelling types throughout the year, with the detached house consistently exhibiting the highest demand both for heating and cooling and the flat the lowest. As



(a)



(b)

Fig. 20. Hourly thermal energy demand during a year of various north-facing dwelling types located in Cardiff: (a) High thermally efficient dwellings (building code '1111') and (b) low thermally efficient dwellings (building code '7654').

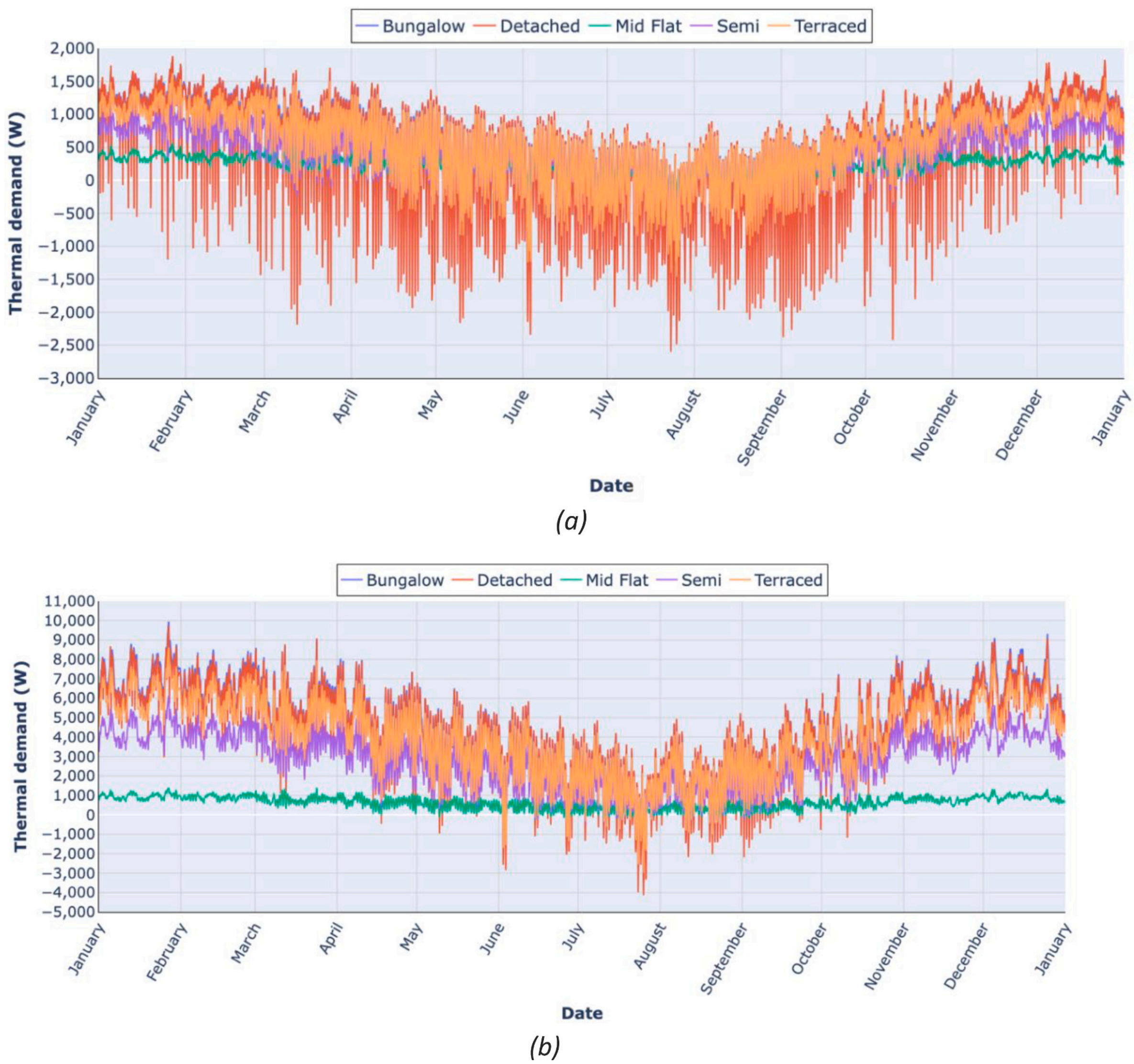


Fig. 21. Hourly thermal energy demand during a year of various north-facing dwelling types located in Newcastle: (a) High thermally efficient dwellings (building code '1111') and (b) low thermally efficient dwellings (building code '7654').

expected, due to typically lower average outdoor temperatures in this geographical location, dwellings located in Newcastle exhibit lower cooling demand than those in Cardiff (see Fig. 20).

6.2. Impact of internal heat gains

Using the base thermal energy demand for a north-facing detached house in Cardiff, the CIBSE TM59 internal load profiles were applied to assess the effect of additional internal heat gains. The results are shown in Fig. 22 for high and low thermal efficiency dwellings.

The inclusion of internal gains affects heating and cooling demand differently across the year. During the winter months, internal gains act as a beneficial heat source, leading to a reduction in heating demand (positive thermal demand) for both dwelling types. This reduction is more pronounced in the thermally efficient dwelling (Fig. 22a), where heat losses through the building envelope are lower and internally generated heat is retained more effectively.

Conversely, during the summer months, internal gains contribute to an increase in cooling demand (negative thermal demand). This effect is substantially stronger in the more thermally efficient dwelling, where the combination of reduced heat dissipation and sustained internal gains leads to an elevated cooling requirement throughout the year. For the less thermally efficient dwelling (Fig. 22b), incorporating internal gains increases the peak cooling demand by approximately 1 kW, while the total number of hours requiring cooling remains broadly similar.

These results demonstrate that improvements in thermal efficiency simultaneously reduce winter heating demand and amplify summer cooling demand, highlighting an important seasonal trade-off. As dwellings become more energy efficient, internal heat gains increasingly influence annual thermal demand patterns, with cooling demand becoming more prominent relative to heating demand, despite heating requirements remaining dominant over the full year.

6.3. Housing estate case study

It is possible to estimate the annual thermal energy demand of a housing estate using the developed database. As an example, a site plan for a newly built community in Cardiff with a total of 172 dwellings was obtained, and the dwelling types and their orientations were tallied. This information is provided in Table 10. For the purposes of data privacy, the name and specific location of the community has been anonymised.

Using this distribution, along with known U-values for new-build dwellings (i.e. building code '1111' corresponding to high thermal efficiencies, see Table 3), the hourly thermal energy demand for each

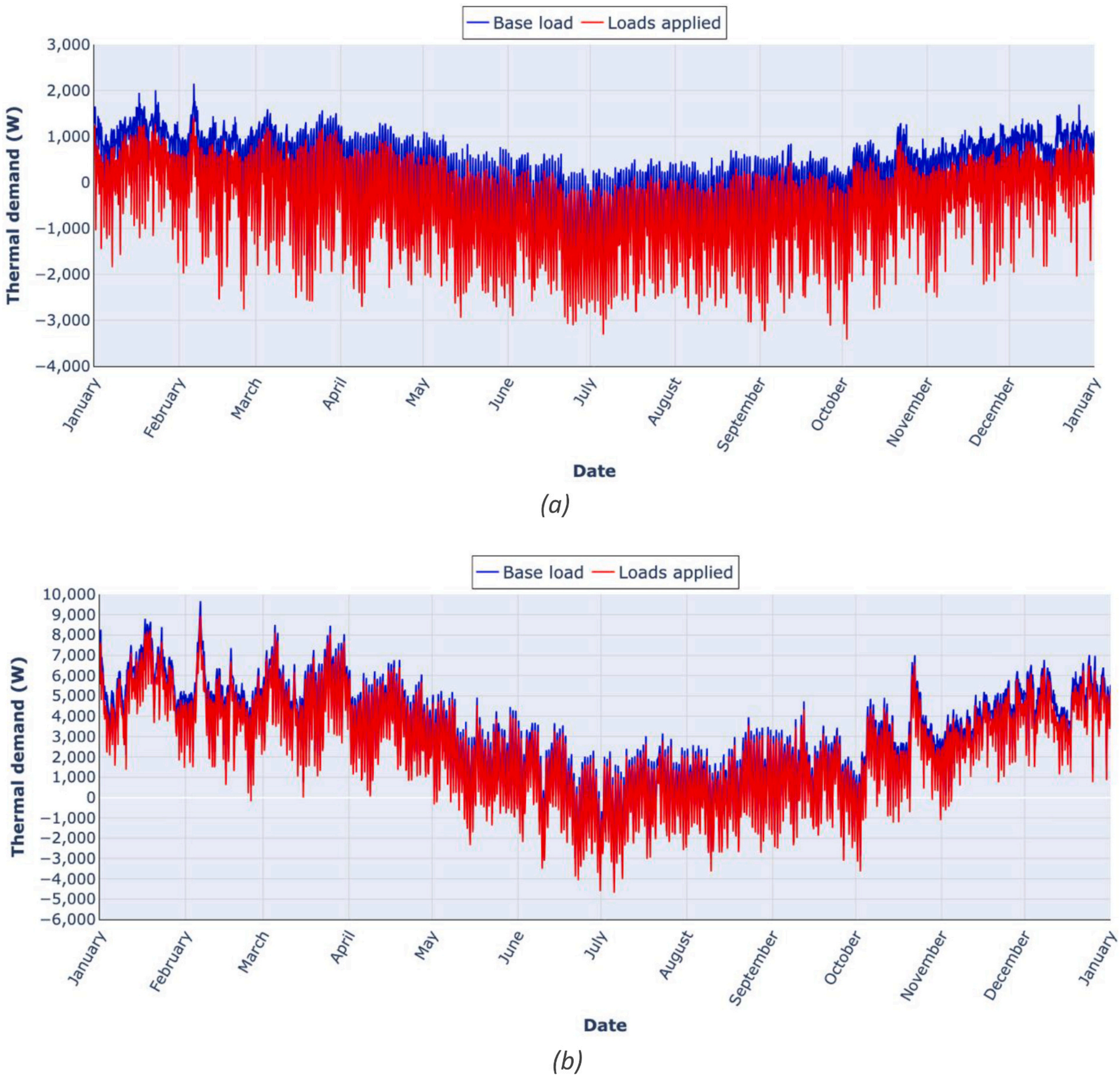


Fig. 22. Comparison of base hourly thermal energy demand with and without internal gains (using CIBSE TM59) for a north-facing detached house in Cardiff: (a) High thermally efficient dwelling (building code '1111') and (b) low thermally efficient dwellings (building code '7654').

dwelling type and orientation was extracted from the database. The total aggregated thermal demand for the estate is shown in Fig. 23. These results do not consider any internal heat gains applied. The peak heating demand, which occurs on February 6th, is approximately 260 kW, while the peak cooling demand on July 7th is about 200 kW. The technology chosen to meet these peaks can have a significant impact on the local electricity distribution network. For example, assuming a coefficient of performance of 3 for a modern variable refrigerant flow system, the peak cooling demand would correspond to a peak electrical load of $\sim$ 66 kW on the local transformer.

Based on these data, the monthly cooling demand of the housing estate for June to September is shown in Fig. 24. For the TMY considered for developing the database, the highest cooling demand occurs in July. Similarly, the monthly heating demand for the estate from December to March can also be evaluated and this is shown in Fig. 25.

It can be observed from Fig. 25 that the highest heating demand occurs in January when using TMY weather files. Even for dwellings with the highest thermal efficiencies considered in this case study, the peak heating demand during winter exceeds the corresponding cooling demand by a factor of ~2.7. This highlights that although cooling demand is emerging and becoming increasingly relevant during summer months, heating demand remains dominant on an annual basis, reinforcing the importance of assessing both heating and cooling within a whole-year thermal demand framework.

7. Limitations

Certain simplifications were adopted in the models to create the thermal energy demand datasets. These simplifications and the associated limitations of the database are discussed in this section.

Indoor set-point temperature.

When developing the thermal energy demand database, a fixed set-point temperature of 21°C was adopted regardless of the type of dwelling or geographical location. In practice, this value would be adjusted throughout the year depending on occupancy and personal preference — and likely depending on the season of the year. A fixed value was here used to maintain consistency and usability across all dwellings and construction combinations.

To provide database users with additional flexibility, a methodology to adjust the thermal demand results for alternative heating or cooling

Table 10
Dwelling type and orientation distribution.

Dwelling	Orientation	Quantity
Terraced (mid)	0°	11
	90°	0
	180°	2
	270°	10
Terraced (end)	0°	8
	90°	0
	180°	2
	270°	10
Semi	0°	18
	90°	22
	180°	30
	270°	10
Detached	0°	13
	90°	7
	180°	17
	270°	12

set-points was provided in Section 5.2. This would enable further analysis into heating and cooling demand without the need to re-run a full set of simulations. Future work, which falls out of the scope of this paper, could expand on this by incorporating realistic energy-management or seasonal temperature schedules.

Effects of shading.

The modelling assumes only self-shading from the dwelling's own geometry (e.g. overhangs, balconies). External obstructions such as neighbouring buildings, vegetation or site-specific urban canyons were not included due to the lack of reliable, scalable geometric data and to keep the simulation space tractable. As a result, solar gains, and therefore cooling demand, may be overestimated for dwellings in heavily shaded urban environments and underestimated for those with unusual façade configurations or reflective surroundings.

Passive strategies.

Dynamic occupant behaviour (e.g. opening windows during night purging, using blinds or curtains) was not included. Windows are assumed closed at all times and no operable shading was modelled. This was chosen to isolate the baseline thermal performance of the envelope and avoid the combinatorial explosion of occupant-driven schedules. Consequently, the dataset may overestimate overheating risk and cooling demand in homes where occupants routinely ventilate or shade spaces.

Energy management.

No adaptive set-point control or smart heating/cooling schedules were included. Each dwelling was simulated with a constant indoor temperature set-point 21°C. Real buildings often feature setback periods, occupancy-based heating or energy management that can reduce annual energy demand. Users of the dataset should be aware that it reflects a steady-state thermal demand profile rather than an operational

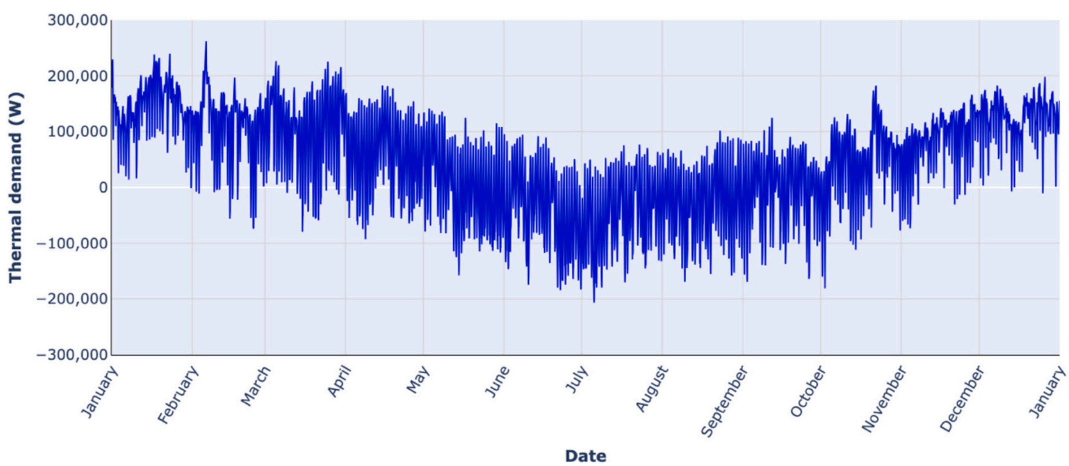


Fig. 23. Total hourly thermal energy demand for a high thermally efficient housing estate in Cardiff.

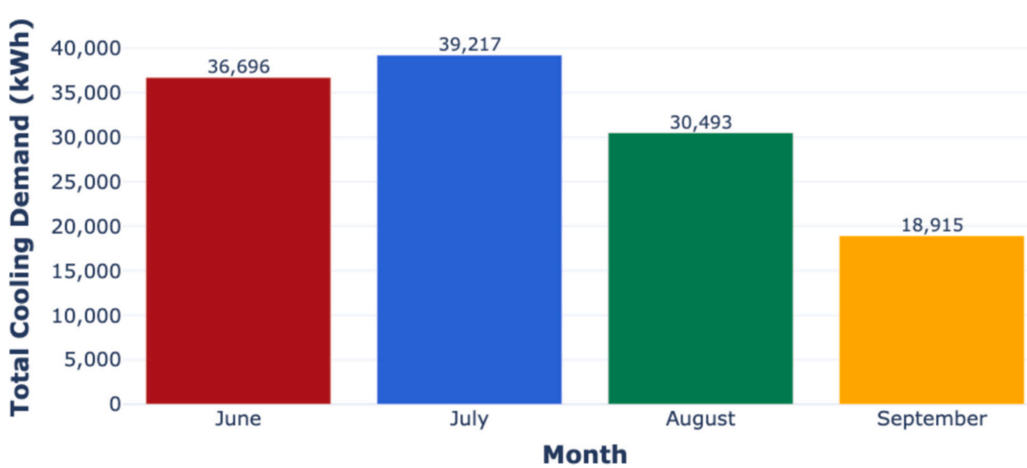


Fig. 24. Monthly cooling demand during June, July, August and September for a high thermally efficient housing estate in Cardiff.

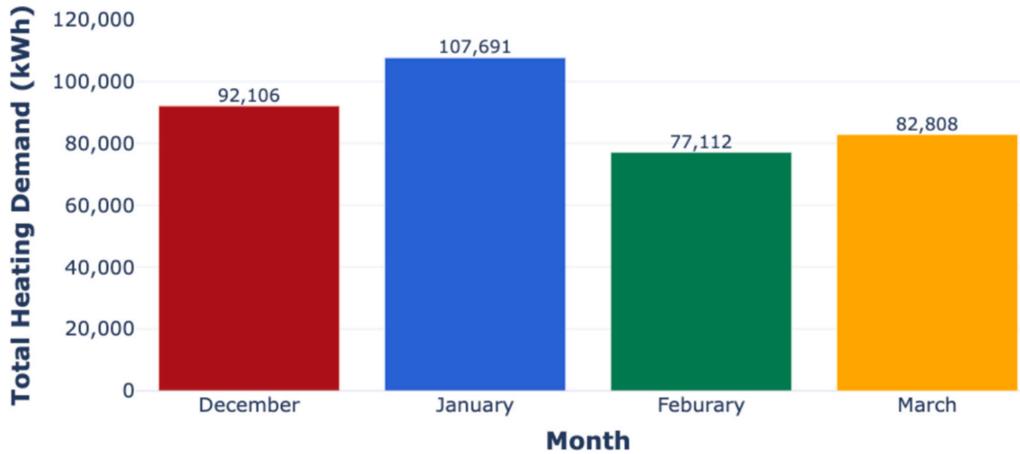


Fig. 25. Monthly heating demand during December, January, February and March for a high thermally efficient housing estate in Cardiff.

one.

Ventilation rates.

Ventilation rates in actual buildings vary depending upon a wide variety of parameters (including wind speed, the differential pressure between indoors and outdoors, door/window openings and air gaps in the construction). Incorporating varying ventilation rates is not possible and therefore a fixed ventilation rate of 0.4 ACH was assumed.

Weather.

The datasets were produced using TMY weather files, representing long-term average conditions for each geographical location (e.g. Cardiff). These files smooth out extreme events and may under-represent future climate volatility or rare but high-impact events such as the 2022 UK heatwave. This approach could be combined with machine-learning models to predict the thermal energy demand of any dwelling type across the UK, supporting estate-level demand assessment for planning and energy infrastructure design. However, this falls out of the scope of the presented work.

Thermal bridging.

Thermal bridging effects were not explicitly modelled. IES VE applies one-dimensional U-values to building elements and does not automatically incorporate linear thermal transmittance (Ψ-values) at junctions. Explicit thermal bridge modelling would require detailed geometry for every junction type and was not feasible given the large number of dwelling variants included in the database. As a result, thermal bridge effects are only indirectly represented through the typical U-values used for each construction.

Internal loads.

Internal heat gains represent a significant source of uncertainty due to the wide diversity of occupant behaviour, appliance usage and lifestyle patterns across households. It is therefore not feasible for this work to represent all possible internal load profiles in a manner that would be representative of the majority of dwellings.

To address this, two illustrative internal load profiles were provided. One follows the CIBSE TM59 internal gain profile, which was specifically designed to represent summer conditions and to assess overheating risk. As this profile deliberately accentuates internal heat gains to emphasise overheating effects, it may not be appropriate for application during winter periods or under more typical year-round operating conditions.

To mitigate this limitation, a simple method for generating custom internal load profiles was provided, allowing users to modify both the magnitude and temporal distribution of internal gains to better reflect alternative occupancy patterns or use cases. Interested database users are therefore encouraged to develop bespoke internal load profiles tailored to their specific research objectives or building use scenarios.

Location.

The thermal energy demand database was generated using a limited set of representative UK locations. As a result, the outputs are only directly valid for those locations and may not accurately reflect dwellings situated in areas with substantially different climates (e.g. coastal regions with milder winters or high-altitude regions with lower temperatures). This limitation arises because each location required separate weather files and a large number of simulations. Expanding the set to include every microclimate in the UK was not computationally feasible.

Future work could incorporate machine learning-based interpolation or predictive models to estimate thermal demand for any UK location using key climatic variables (such as temperature, solar radiation and wind speed). This would allow the database to support analyses across the full range of UK weather conditions without requiring exhaustive physics-based simulations.

The thermal energy demand database is currently restricted to the UK domestic sector, selected geographical locations within the UK and prevalent UK climate. This is because the database was developed as a UK-wide, openly accessible resource of thermal energy demand data for the national housing stock. This resource was previously non-existent — and thus can potentially serve as an evidence base to assess growing thermal demand in a warming climate to support researchers, home developers, building designers and policymakers. Although extending the approach to other dwelling types and climates in other parts of the world would be of great benefit, this exercise falls out of the scope of this paper.

8. Conclusions

This paper presented a comprehensive, high-resolution, scalable and openly available database of yearly thermal energy demand for typical UK dwellings, covering both heating and cooling requirements. The database has been produced using a validated, physics-based modelling approach supported by building modelling software which adheres to international standards. The methodology incorporates representative dwelling archetypes, construction methods, orientations and six key UK climatic locations. By standardising U-value combinations and encoding them as dwelling codes, users can easily retrieve and compare thermal performance across a wide range of building envelope efficiencies.

The work fills a critical data gap: while UK heating demand had been relatively well documented, a systematic quantification of domestic cooling demand had previously received limited attention despite its growing relevance under a warming climate. At the same time, the intrinsic interdependence between heating and cooling requirements in buildings had not been accounted through a single and self-contained resource enabling detailed studies over a full year temporal coverage.

The results presented in this paper, facilitated through the developed thermal energy demand database, show that cooling demand emerges in both high-efficiency and low-efficiency dwellings for different reasons: thermally efficient homes exhibit a more persistent, low-level cooling requirement throughout the year, whereas less efficient homes experience higher but more intermittent cooling peaks. This underscores the importance of integrating cooling considerations into building design, overheating assessments and energy infrastructure planning, as the need for cooling can play a more significant role relative to heating needs. Results however also demonstrate a seasonal trade-off: as thermal efficiency increases, winter heating demand may reduce while simultaneously summer cooling demand may intensify. Giving consideration to internal gains further amplifies this effect.

The representative estate case study demonstrates that summer cooling peaks can already approach the magnitude of winter heating peaks, reinforcing the need for proactive planning as the UK climate warms. However, despite the emerging and increasingly relevant cooling demand during summer months, heating demand is prevalent on an annual basis. This highlights the need to assess both heating and cooling within a whole-year thermal demand framework which accounts for seasonal variations, as interventions aimed at reducing cooling demand and mitigating overheating effects during summer may inadvertently increase heating demand over winter.

The dataset supports a wide range of applications, including:

- **Policy and planning:** informing strategies to decarbonise heating and cooling while maintaining grid reliability.
- **Energy infrastructure design:** estimating peak loads and identifying local network reinforcement needs.
- **Building design and retrofit:** enabling early-stage thermal load estimation and compliance with standards such as those in Part O of Building Regulations.
- **Research and forecasting:** supporting model development, sensitivity analyses and scenario testing under future climates.
- **Homeowner guidance:** offering insight into potential heating and cooling requirements.

Although certain simplifications were necessary to develop the presented database (e.g. fixed ventilation rates, no external shading, closed-window operation), this resource provides a robust foundation for year-round large-scale heating and cooling assessments in UK domestic dwellings. The framework can be refined further by incorporating internal gains, modifying thermostat set-points or applying advanced energy management and passive cooling strategies.

By making these +220,000 hourly datasets publicly accessible, this work enables interested stakeholders, from policymakers to engineers, architects and researchers, to better understand and plan for the evolving thermal energy landscape of UK housing in a warming climate.

CRediT authorship contribution statement

Lloyd Corcoran: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation. **Pranaynil Saikia:** Writing – original draft, Supervision, Methodology, Investigation, Formal analysis. **Carlos E. Ugalde-Loo:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization. **Muditha Abeysekera:** Supervision, Project administration, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

The work presented in this paper was supported by the Engineering and Physical Sciences Research Council (EPSRC), UK Research and Innovation, through the project 'Flexibility from Cooling and Storage (Flex-Cool-Store)' under grant EP/V042505/1.

Data availability

The thermal energy demand database reported in this paper has been made available in the Cardiff University data repository at 10.17035/cardiff.30305833.

References

[1] Department for Energy Security and Net Zero, 'Energy consumption in the UK 2023',. Accessed: July 03, 2024. [Online]. Available: https://www.gov.uk/government/statistics/energy-consumption-in-the-uk-2023; 2023.
[2] Lowe JA, et al. UKCP18 science overview report. Met Off Hadley Cent Exeter UK 2018:1–73.
[3] Lawson A. UK heatwave prompts National Grid to fire up coal plant to meet aircon demand. The Guardian, 12th June 2023. Accessed: July 03, 2024. [Online]. Available: https://www.theguardian.com/environment/2023/jun/12/uk-heatwave-prompts-order-to-fire-up-coal-plant-to-meet-aircon-demand.
[4] Department for Energy Security and Net Zero; Ofgem, 'Statutory Security of Supply Report: 2024', Department for Energy Security and Net Zero; Ofgem, London, UK [Online]. Available, https://www.gov.uk/government/publications/statutory-security-of-supply-report-2024; 2024.
[5] Department for Business, Energy & Industrial Strategy, 'Cooling in the UK'. Accessed: Mar. 08, 2024. [Online]. Available, https://www.gov.uk/government/publications/cooling-in-the-uk; 2021.
[6] English Housing Survey 2023 to 2024: climate resilient homes – fact sheet. GOV.UK. Accessed: Sept. 26, 2025. [Online]. Available, https://www.gov.uk/government/statistics/english-housing-survey-2023-to-2024-climate-resilient-homes-fact-sheet/english-housing-survey-2023-to-2024-climate-resilient-homes-fact-sheet.
[7] Department for Energy Security and Net Zero, 'Energy Follow-Up Survey (EFUS) overheating in homes', UK [Online]. Available: https://www.gov.uk/government/publications/energy-follow-up-survey-efus-overheating-in-homes; 2024.
[8] Corcoran L, Saikia P, Ugalde-Loo CE, Abeysekera M. An effective methodology to quantify cooling demand in the UK housing stock. Appl Energy 2025;380:125002. https://doi.org/10.1016/j.apenergy.2024.125002.
[9] Department for Levelling up, Housing and Communities, 'English Housing Survey 2021 to 2022: headline report', 2022. Accessed: Mar. 20, 2024. [Online]. Available: https://www.gov.uk/government/statistics/english-housing-survey-2021-to-2022-headline-report/english-housing-survey-2021-to-2022-headline-report.
[10] Chen T, et al. A review on electric vehicle charging infrastructure development in the UK. J Mod Power Syst Clean Energy 2020;8(2):193–205. https://doi.org/10.35833/MPCE.2018.000374.
[11] National Grid. Network capacity map. Accessed: Nov 12, 2024. [Online]. Available, https://commercial.nationalgrid.co.uk/our-network/network-capacity-map/.
[12] HM Government. The Building Regulations 2010 - The Merged Approved Documents. Accessed: Mar. 21, 2024. [Online]. Available, https://www.gov.uk/guidance/building-regulations-and-approved-documents-index; 2023.
[13] CIBSE. Guide A: Environmental design. Accessed: Mar. 08, 2024. [Online]. Available, https://www.cibse.org/knowledge-research/knowledge-portal/guide-a-environmental-design-2015; 2021.
[14] Rightmove. Rightmove. Accessed: Apr 30, 2024. [Online]. Available, https://www.rightmove.co.uk/.
[15] Integrated Environmental Solutions. Software Validation and Approval | IES Virtual Environment. Accessed: Mar. 28, 2024. [Online]. Available, https://www.iesve.com/software/software-validation.
[16] Littlefair PJ. Site layout planning for daylight and sunlight: A guide to good practice. 2nd ed. Watford, UK: Building Research Establishment (BRE Press); 2011.
[17] Climate One Building. Repository of free climate data for building performance simulation. Accessed: Mar 21, 2024. [Online]. Available, https://climate.onebuilding.org/default.html.
[18] Solargis. Solar resource maps of United Kingdom. Accessed: Mar. 21, 2024. [Online]. Available, https://solargis.com/maps-and-gis-data/download/united-kingdom.
[19] UK Met Office. 'Location-specific long-term averages', Met Office. Accessed: Nov 24, 2025. [Online]. Available, https://www.metoffice.gov.uk/research/climate/maps-and-data/location-specific-long-term-averages/gcpevmgzn.
[20] CIBSE. Technical Memorandum 59: Design methodology for the assessment of overheating risk in homes | CIBSE. Accessed: Mar. 20, 2024. [Online]. Available, https://www.cibse.org/knowledge-research/knowledge-portal/technical-memorandum-59-design-methodology-for-the-assessment-of-overheating-risk-in-homes; 2017.
[21] Office for National Statistics.. Time Use in the UK. Accessed: June 20, 2024. [Online]. Available, https://www.ons.gov.uk/peoplepopulationandcommunity/pe

rsonalandhouseholdfinances/incomeandwealth/bulletins/timeuseintheuk/march2023; July 2023.
[22] Integrated Environmental Solutions. ApacheSim calculation methods. Accessed: Mar. 14, 2024. [Online]. Available, https://www.iesve.com/downloads/help/Thermal/Reference/ApacheSimCalculationMethods.pdf.
[23] Roberts BM, et al. Predictions of summertime overheating: comparison of dynamic thermal models and measurements in synthetically occupied test houses. Build Serv Eng Res Technol 2015;40(4):512–52. https://doi.org/10.1177/0143624419847349.
[24] James G. An introduction to statistical learning with applications in Python. In: In springer texts in statistics. 1st ed.2023. Cham: Springer International Publishing; 2023. https://doi.org/10.1007/978-3-031-38747-0.
[25] Dubai Government. Green Building Regulations and Specifications [Online]. Available, https://www.dm.gov.ae/wp-content/uploads/2018/01/05_ENG_DCL_LawsLegislation_EngineeringSection_GreenBuildingRegulation.pdf; 2011.