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Quantifying the impact of Covid-19 on the energy consumption in the low-income housing in Greater London

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Abstract. Covid-19 has caused great challenges to the energy sector, particularly in residential buildings with low-income households. This study investigates the impact of the confinement measures due to the Covid-19 outbreak on the energy demand of seven residential archetype buildings in Greater London. Three levels of confinement for occupant schedules are proposed and compared with the base case before Covid-19. The archetypes, their boundary conditions, and input parameters are set up according to statistics from English Housing Survey (EHS) sample data for low-income housing. The base case scenario (normal life without confinement measures) is validated against the measured data energy consumption from the National Energy Efficiency Data-Framework (NEED) statistics. The results show that electricity consumption is significantly lower than that for heating and hot water for all the archetypes. By comparing the base case scenario with the full Covid-19 lockdown scenario, the results indicate that heating and hot water consumption (kWh) for all the residential archetypes increases, on average, by 10%, and total electricity demand (kWh) increases by 13%. The study highlights the importance of introducing detailed occupancy profiles in multi-zone building energy simulation models during a pandemic that leads to a greater shift towards home working, which may increase the risk of fuel poverty in low-income housing.

Keyword: Covid-19; energy demand, residential building archetype; low-income housing

1. Introduction

The Covid-19 outbreak has had a profound impact on various aspects of life, including the global economy, social connections, the environment, and energy consumption and supply [1]. The International Energy Agency (IEA) reports that the Covid-19 pandemic caused the largest disturbance to energy consumption in the past 70 years, with an estimated reduction of 6% in global energy consumption in 2020 compared with 2019 [1]. In the UK, the government implemented a national lockdown from 23 March to 10 May 2020 and followed by a second lockdown in November. These lockdowns and associated restrictions significantly affected human mobility and, particularly, the level of occupancy in residential buildings. UK subnational (region and local authority district) electricity and gas consumption statistics show an overall 5.6 % increase in electricity consumption and a 3.3 % increase in gas consumption in residential buildings during the first lockdown [3]. However, there were significant changes in the daily electricity consumption as a function of time compared with the pre-Covid-19 periods. The daily life and behavioural patterns of individuals changed notably during the pandemic. The time spent at home particularly increased for those of age over 65 [4], which were particularly protected, as well as low-income families. Furthermore, many workers and students were encouraged to work or study at home, which commonly increased the residential use of computers and tablets [5]. As a result, people spent more time at home, leading to significant changes in their daily habits [7], which increased residential heating and electricity energy consumption, and thus carbon dioxide emissions in many countries. Addressing these changes and their impact on energy demand is crucial for developing sustainable energy strategies for residential buildings during and after pandemics [8-9]. The aim of the present study is to develop a methodology to analyse the impacts of Covid-19 lockdown measures on the energy consumption (electricity and heat consumption) for 7 UK housing archetypes, namely Bungalow, Converted flat, as well as Detached, Semi-detached, Mid-terrace, End-terrace, and Low-rise buildings, during the first lockdown period. The focus is on changes in residential occupant density (usable area per person) and occupancy schedules for different confinement scenarios. The aims are (1) to validate the simulated energy consumption (heating, hot water energy, and electricity consumption) against the National Energy Efficiency Data-Framework (NEED) statistics for each housing type and (2) to compare the total energy consumption of the different housing types.

2. Data and method

2.1 Data

To gain insights into the impact of policies implemented to combat COVID-19, we retrieved Google Mobility data [10] on the movement of individuals across various geographic locations, including residential areas, over time for Greater London This dataset shows the relative percentage of changes in duration (hours) spent in places of residence to a baseline period (before Covid-19) for each day from February during the year of 2020. The dataset baseline is calculated as the median value for the corresponding day of the week during the period from 3 January to 6 February 2020. The data shows relative changes, but not the absolute duration, and were collected for Greater London on a daily base.

Table 1. The EHS building characteristics used as model input

Building Archetypes	Floor area (m^2)	U-value [W/m^2K]*
Semi-detached	51.59	Wall: 2.05 Roof: 0.61 Floor: 3.19 Windows: 0.21 **The U values are selected for different range according to the most common U value in our sample data for wall, roof, floor, and windows.*
End-Terrace	45	
Mid-Terrace	45	
Bungalow	70	
Detached	70.96	
Converted Flat	72.28	
Low rise flat-Pre1990 (12 flats)	51.8	

We use the English Housing Survey (EHS) sample data [11] to provide detailed information on (i) the geometrical characteristics of each residential building archetype (e.g., the building footprint, number of floors, height, and volume), and (ii) thermal properties of the construction layers (e.g., roof, floor, window and wall U-values and presence of cavity/solid walls; material properties, thickness (m), and conductivity, W/mK) (Table 1).The EHS sample of Greater London consists of 337 low-income homes among nearly 2000 home sample. We focus here on the low-income homes. We utilised an hourly weather file for a typical meteorological year (TMY) to simulate the energy consumption of building archetypes under the base case (no-Covid) occupancy schedules for Greater London. To incorporate more realistic scenarios, we further employed an hourly weather file for Greater London in 2020 to simulate the energy consumption of the building archetypes for three different occupancy schedules (18 hrs, 21 hrs, and 24 hrs). The weather files were obtained from Meteonorm version 8.

We define three occupancy profiles (Table 2) to evaluate the effect of the Covid-19 pandemic on the energy consumption of the residential archetypes in addition to that of the base case (no Covid). For each occupancy schedule, we considered detailed activities of residence inside each micro-environment (living room, dining room, kitchen, bath, bedroom, entrance). More specifically, we considered (i) the hours of operation of the energy system during winter and summer and for lighting, cooking, television, laptop, fridge, and exhaust fan, (ii) the internal heat gains due to the presence and activity of people in the building, and (iii) the heat losses (due to window openings). We define the following confinement scenarios: (i) a base case scenario, in which the energy consumption was simulated considering the occupants' normal schedule (a full time worker) in a typical year according to [10], with the assumption that people stay at home 14 h per day; (ii) and (iii) partial lockdown scenarios, during which people stay at home 18 h per day and 21 h per day, respectively; (iv) a full lockdown scenario, during which people stay at home all day (24 h per day). Activities to define for the occupancy schedules during the Covid-19 are limited and they are partly collected from survey data [12]. In the heating system, a gas boiler was defined with a setpoint temperature of 21°C for heating [13] and 26°C for cooling. For zones within the range of 21-24°C outside temperature, controlled natural ventilation was assumed. The boiler flow temperature was set to 65°C according to UK guidelines. We assume that in all these scenarios the heating system was switched on/off to ensure thermal comfort conditions, as a function of the outdoor temperature and the defined occupancy schedules. We also assume that from 1 May until 30 September the heating system is totally off.

Table 2. Definition of different occupancy schedules due to the different confinement scenario during Covid-19

Scenario	Occupancy schedule
Base case - no Covid-19 case	Normal schedule (e.g., full time working; 14 h)
Confinement level 1 - partial lockdown	18 h (6 hrs unoccupied)
Confinement level 2 - partial lockdown	21 h (3 hrs unoccupied)
Confinement level 3 - full lockdown	24 hr at home

The measured annual energy consumption (domestic gas and electricity consumption) for different building archetypes were obtained from National Energy Efficiency Data-Framework (NEED) statistics [14]. The data are used to validate the simulated results.

2.2. Energy consumption simulation using EnergyPlus

The multi-zone 3D models of the residential building archetypes were constructed using Grasshopper. The hourly energy consumption profiles were simulated with EnergyPlus engine using Ladybug Tools Plugin. The modelling and simulation procedure is done in Grasshopper. The analysis focused on the impact of residential occupant density (usable area per person) and daily occupancy schedules corresponding to different confinement scenarios.

3. Results

3.1 Change in residential building occupancy using Google mobile data

Our analysis from location-based mobile phone data shows (Figure 2) the percentage of changes in duration (hours) spent in places of residence in the greater London from the middle of February 2020 (before lockdown) to April (during lockdown) and then to December 2020. We show that the percentage increase in people staying at home during this period was on average 17% with a maximum of 38%. The percentage increase in people staying at home during the first lockdown (from 23 March to 10 May 2020) was, on average, 29% and during the second lockdown (from 5 November to 2 December) on average 18%.

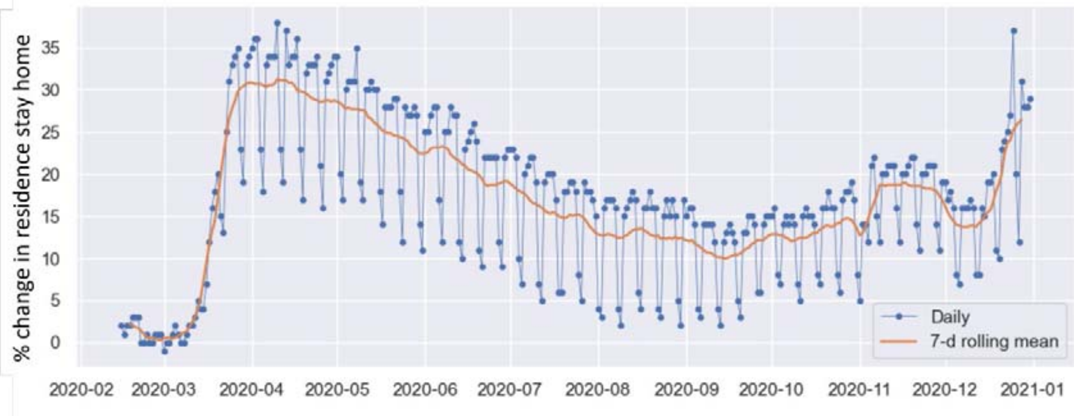

Figure 1. Google mobile data showing the percentage change of people staying at home during the year 2020 during the first lockdown and the second lockdown in the Greater London.

3.2 Energy consumption simulation results and their validation

The results indicate changes in household energy consumption (kWh) during the full lockdown period when compared with pre-lockdown (base case scenario) for each housing archetype. More specifically, the Converted Flat archetype experienced the highest increase in heating demand (23%), while the End-Terrace archetype saw the lowest increase in heating demand (6%). The highest increase in electricity demand (kWh) was observed in the End-Terrace archetype (23%), while both the Semi-Detached and Converted Flat archetypes had the lowest increase (3% increase). The reasons for these differences in observed changes in energy consumption may be partly related to building geometry, floor area, building age, and surface-to-volume ratio of each archetype as well as the occupancy profiles – these will be explored further as this study continues. Figure 3 illustrates the average energy consumption in kWh/m^2/year for the base case (no Covid-19) and for the three different confinement levels. The demand for electricity was significantly lower than that for heating and hot water for all archetypes. During the full lockdown, the Converted Flat archetype was the most affected by confinement as regards heating and hot water energy consumption (kWh/m2/year), while the End-Terrace archetype was the least affected.

We used data from NEED [14] to validate the energy consumption simulation (kWh/year) for each building archetype and for the base case occupancy scenario (Figure 4). The percentage difference of energy consumption between the measured data and the simulated results varied across archetypes. For the heating and hot water energy consumption, the difference between measured and simulated results ranges from ± 2% to ± 8%. For the electricity consumption, the difference between measured and simulated results ranges from ± 3% to ± 23%. The Detached archetype had the highest heating and hot water energy consumption, consistent with the measured data, while the Low-rise flat had the lowest heating and hot water energy consumption, also consistent with the measured data. Detached archetype also has the highest electricity

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consumption, in line with the measured data, while the Low-rise flat and End-terrace archetype had the lowest electricity consumption (the measure data show the Low-rise has the lowest energy consumption).

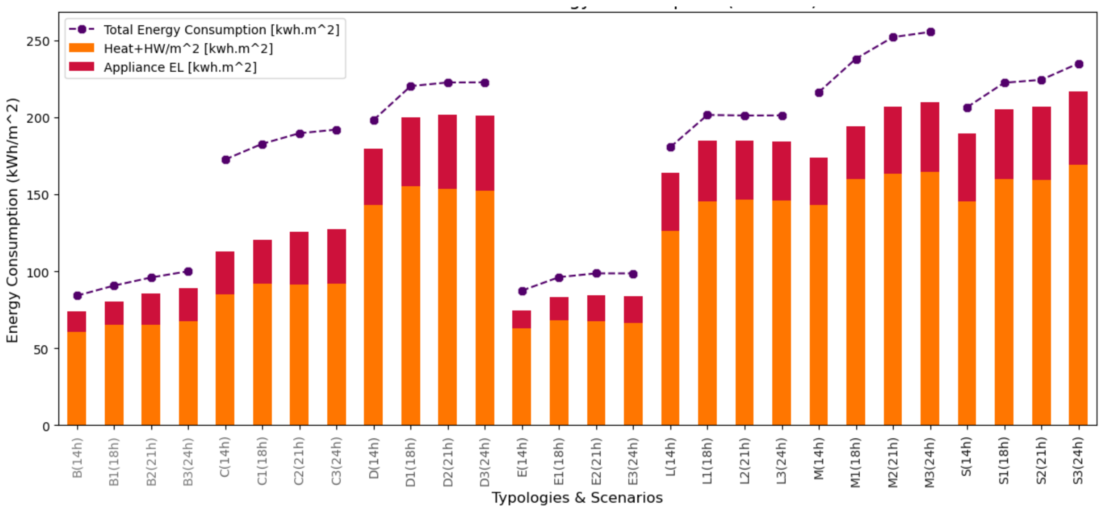

Figure 2. Heating and hot water energy consumption, kWh/m²/year, total electricity consumption, kWh/m²/year (equipment and lighting) for the case Base scenario and the three confinement scenarios: level 1, 2, 3 (Table 2). B: Bungalow; C: Converted flat; D: Detached; E: End Terrace; L: Low Rise; M: Mid Terrace; S: Semi-detached.

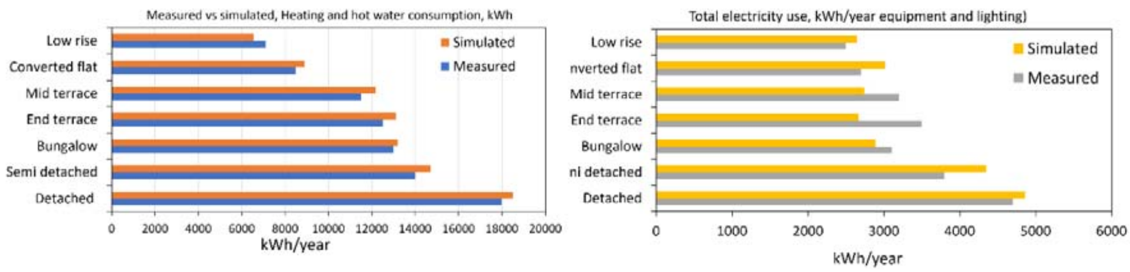

Figure 3. Validation of energy consumption/demand (heating & hot water and electricity consumption) with the measured data for each residential building archetype.

4. Conclusion and future work

This study evaluated the impact of Covid-19 confinement measures on the energy consumption/demand of 7 residential building archetypes in Greater London, considering different occupancy schedules. By comparing the base case scenario (normal life without confinement measures) with the full lockdown scenario, the results show an average increase of 10% in heating & hot water consumption/demand (kWh) and 13% in total electricity consumption/demand (kWh) for all residential archetypes. The study highlights the importance of incorporating detailed occupancy profiles in multi-zone building energy simulation models during a pandemic. With the increasing trend towards working from home during pandemics, the study also raises concerns about the risk of fuel poverty in low-income housing. In a future work, the plan is to assess the resilience of the UK's low-income housing sector to the combined effects of climate change and pandemics. This will involve simulating the energy consumption of 7 residential archetypes under future climate scenarios (2040-2069), considering extreme climate conditions (e.g., heat waves and cold snaps), different occupancy schedules, and retrofitting scenarios for net-zero emission buildings. By identifying residential clusters with the percentage of each building archetype in Greater London, the present study can be expanded from the building level to the city level, with a focus on low-income households. This is crucial for future energy planning and policymaking, considering the complexities and interconnections of extreme events [15], including wars (such as in Ukraine), particularly for low-income households, in achieving the energy and climate targets set for 2050.

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