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The Effect of Covid-19 Pandemic on Energy Demand, Carbon Emission and Household Budget of Households in England due to Working from Home.

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ABSTRACT

The Covid-19 pandemic situation is forcing people to work from home due to lockdown; and as a result, there will be an effect on domestic energy consumption as well as carbon emission, particularly during winter. This paper investigates the change in energy demand, household budget and Carbon emission in upcoming winter of 2020/2021 due to the new patterns of working from home. The results show that a family with well insulated house that normally use a car or more to travel, will not be affected significantly in terms of their household budget; and the increase of carbon emission from heating will be compensated by the reduction in car use. For a family with poorly insulated house who do not travel long distances to work, the lockdown will cause more strain on their budget and they will be consuming more energy for heating and hence producing more carbon emission. The novel methodology implemented can be used to assess energy poverty and the effect of Covid-19 on households in other countries.

Keywords: Carbon emission; heating; energy poverty; working from home; Covid-19; coronavirus.

NONMENCLATURE

A	*Area of a building's wall exposed to external environment*
D	*Average number of weekdays in a month*
H	*Hours of operation*
Q	Heat loss
U	U-value
T_{in}	Indoor Temperature
T_{out}	Outdoor temperature
E_h	Heating energy demand
E_e	Electricity demand
P	Power required by an electric appliance

1. INTRODUCTION

Space heating during winter is responsible for high energy consumption in buildings [1]. Limited research has been done in this area due to its infancy. During current pandemic situation of Covid-19 the energy demand is likely to increase further in winter as the majority of people are working from. As a result, the number of households suffering from energy poverty is expected to increase. However, there could be savings in travel expenses due to working from home which would allow some households to recover the increased cost of energy bills. Well-insulated buildings are energy efficient in terms of heating demand. Therefore, households living in such buildings are less likely to suffer from the increased energy bills; rather they may gain some savings from the reduction in travel expenses. Moreover, the increase in energy demand will be responsible for excess carbon emission. On the other hand, the reduction in travelling will reduce that part of the household carbon emission. This paper investigates the expected increase in energy demand during winter of 2020/2021 in the UK (England) due to working from home and the effect on household budget and carbon emission.

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2. METHODOLOGY

The heat loss through a building's wall depends on the thermal transmittance, known as the U-value, the area of the wall exposed to external environment and the temperature difference between indoor and outdoor environments; and therefore, the heat loss can be estimated using equation (1) [2].

$$Q = UA(T_{in} - T_{out}) \quad (1)$$

Assuming the heating energy consumption is equal to the amount of heat loss through the building's wall, the heat demand for a building can be estimated from equation (1). It is assumed that if people are travelling to work, their home will be unoccupied therefore the indoor temperature will be at about 15°C; and if they are working from home then the indoor temperature will be at about 21°C. In this paper, U-values as in Table 1 are used in the calculations [3].

Table 1: U-value of different wall types.

Wall Types	U-value (W/m^2K)
Solid wall in very old buildings	2.30
Solid wall in old buildings	1.70
Unfilled cavity wall	1.50
Solid wall with 100mm thick external insulation	0.32
Filled Cavity wall with 100 mm thick external insulation.	0.25

A low U-value is desirable as it restricts heat transfer through walls. Based on the external temperature distribution from October 2019 to March 2020 [4], the excess heating energy demand is calculated for different dwelling types between 9:00 and 17:00 on weekdays using equation (2).

$$E_h = \sum(Q_{21} - Q_{15}) \times 10^{-3} \ \ kWh \quad (2)$$

The number of weekdays between October 2019 and March 2020 is considered for the estimation of the change in monthly energy demand. It is assumed in this paper that all buildings are centrally heated by gas fired boilers. The use of electric appliances such as TVs, desktops, laptops, lighting and electric kettles for boiling water to make tea/coffee are responsible for the excess in electricity demand during the same period; and considering the average number of weekdays per month the monthly electricity demand is estimated using equation (3).

$$E_e = P \times H \times D \times 10^{-3} \ \ kWh \quad (3)$$

Electricity consumptions for a 42-inch LCD TV is 120 watts [5] and for a desktop and a laptop is circa 150 watts and 120 watts respectively [6]. It is assumed on average there are 5 lights in operation of 60 watts each for lighting a house during working hours. It generally takes about 2 minutes and 45 seconds to boil 1 liter of water at room temperature with a 2 kW electric kettle [7]. The increase in energy bills for different type of dwellings are calculated by multiplying E_h and E_e with the unit cost of energy which is 3.9 pence per kWh for gas [8] and 14.37 pence per kWh for electricity [9]. Similarly, CO_2 emissions due the increased energy demand are calculated by multiplying E_h and E_e with the CO_2 emission rate due to the production of the required energy which is 0.277 kg per kWh for electricity consumption [10] and 0.203 kg per kWh for gas consumption [11]. To estimate the travelling expenses and associated reduction in carbon emission, only car mileage is considered. Fuel cost per mile for petrol is 12 pence and for diesel is 10 pence considering 1400 cc to 2000 cc engine [12]; and average carbon emission by a newly registered car in the UK is 121.3 grams/km [13] which is equivalent to 0.195 kg/mile.

3. RESULTS AND DISCUSSION

Table 2 shows the average increase in heating energy demand due to working from home in different dwellings of different wall types and U-values of Table 1.

It can be noticed from Table 2 that the uninsulated solid wall buildings require more than 5 times the average energy to maintain comfortable indoor temperatures when compared with the 100mm thick externally insulated buildings; and for the worst case scenario, it would be 8 times higher in very old buildings with U-value of 2.3 W/m^2K. Table 2 also shows that detached houses have the highest increase in energy consumption in all wall types; this is because they have the highest amount of wall surface area exposed to the external environment compared to the other type of houses. If we look at the broad picture of country-wide increase in heating energy demand in uninsulated solid wall buildings as presented in Table 3, it is found that those buildings would be responsible for the consumption of about 1499.91 Gwh of additional energy per month for heating during winter. Considering those buildings to be centrally heated by gas boilers, the consumption of additional heating energy will release circa 304.48 Mt (million ton) of CO_2 in the environment in each winter month.

Table 2: The increase in heating energy demand (kWh/month) in different dwelling types with different wall types).

U-value of wall (W/m²K)	2.30	1.70	1.50	0.32	0.25
End terrace (kWh/ month)	415.47	307.06	270.94	57.80	45.16
Mid terrace (kWh/ month)	310.10	229.19	202.22	43.14	33.70
Semi detached (kWh/ month)	478.70	353.79	312.17	66.60	52.03
Detached (kWh/ month)	773.74	571.85	504.57	107.64	84.10
Bungalow (kWh/ month)	457.62	338.22	298.43	63.66	49.74

Table 3: The increase in average monthly energy demand of dwellings with solid wall construction (mean U-value of 1.7 W/m²K)

House Type	**Wall surface area exposed to outdoor (m²)**	**Number of dwellings [14]**	**Average energy demand (GWh/ month)**
End terrace	138	874,000	268.37
Mid terrace	103	1,725,000	395.34
Semi detached	159	1,265,000	447.55
Detached	257	598000	341.97
Bungalow	152	138,000	46.67
Total			**1499.91**

Table 4 represent the average monthly increase in electricity demand per household as a result of working from home. The excess electricity demand would result in £17.97 increase in monthly electricity bills per household and it is also responsible for circa 34.63 kg of CO_2 emission per household in each winter month. As a result, 2994.52 Gwh additional electricity demand per month would arise from 23.95 million households in England [15] and this additional electricity consumption would be responsible for the release of 829.48 Mt of CO_2 per month.

Table 4: The estimated average increase in monthly electricity demand per household

Appliance	**Quantity**	**Power (Watt)**	**Duration (hours)**	**Average electricity demand (kWh/ month)**
TV (42" LCD)	1	120	8	20.96
Desktop	1	150	8	26.20
Laptop	2	50	8	17.47
Lighting	5 lights	60	8	52.40
Electric Kettle	4 litres a day	2000	0.046	8.01
Total				**125.03**

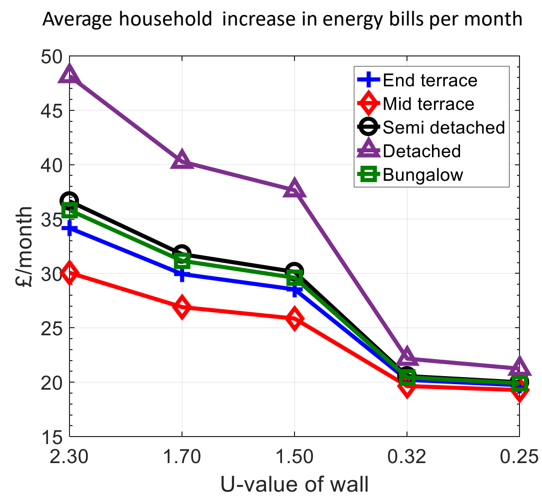

Figure 1: Average increase in energy bills per month.

Figure 1 shows the average increase in energy bills per month in different dwelling types due to working from home. It is found from Figure 1 that the difference in energy bills between a modern detached house having filled cavity wall with external insulation and an old detached house with no insulation could be as high as £27.90 per month. The differences in energy bills among the mid terrace houses with different U-values are less severe as they have the least amount of wall surface area exposed to the external environment. The houses that are externally insulated, will experience a rise in the heating energy bill by as little as £1.31 to £4.20 a month depending on the dwelling type. On the other hand, occupants of uninsulated houses will be facing a significant rise in the heating energy bill ranges from

£7.89 to £30.18 per month depending on the dwelling type.

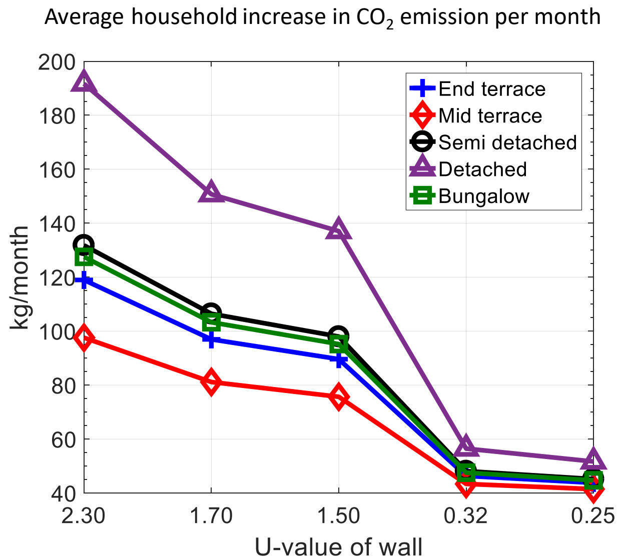

Figure 2: Average increase in CO_2 emission per month.

Figure 2 shows the average increase in CO_2 emission per month from each dwelling types with different U-values. Like Figure 1 it is also observed that an old detached house with uninsulated solid walls could responsible for emitting 195 kg of excess CO_2 per month. On the other hand, a modern detached house with U-value of 0.25 W/m^{2}K is responsible for emitting less than 60 kg CO_2 per month. The increased expenditure in energy bills is likely to be offset by the reduction in travelling expense due to working from home. According to Department for Transport [16], the average use of car is reduced by 67% between 24th March and 24th April 2020 due the Covid-19 situation. Based on average car mileage [17], the monthly reduction in mileage travelled by a car will be 413.17 miles. At this mileage reduction rate each car contribute to the reduction of 80.66 kg of CO_2 emission per month and total reduction in CO_2 emissions from 32.88 million cars in the UK [18] is estimated to be 2652.30 Mt.

Figure 3 shows the average savings per month in different dwelling types with different U-values of walls. The solid lines represent the savings by a typical household uses two cars and the dashed lines represent the savings by a typical household uses one car for travelling. It is noticed form Figure 3 that a household with a single car in an old detached house with uninsulated solid walls is spending all their savings from travelling to pay the energy bills. On the other hand, households belong to modern insulated houses with wall U-value of 0.25 W/m^{2}K are likely to save £30 a month if they are using one car and £80 a month if they are using two cars.

Figure 4 shows the net CO_2 emissions per month in different dwelling types with different U-values of walls due to working from home. Again, the solid lines represent the household using two cars and the dashed

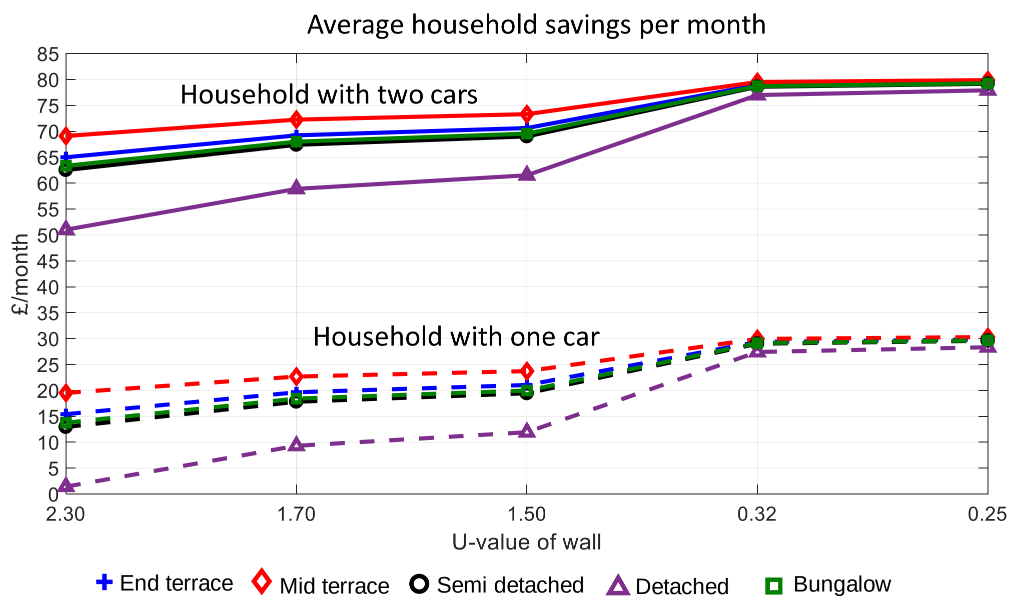

Figure 3: Average household savings per month based on house type and number of cars.

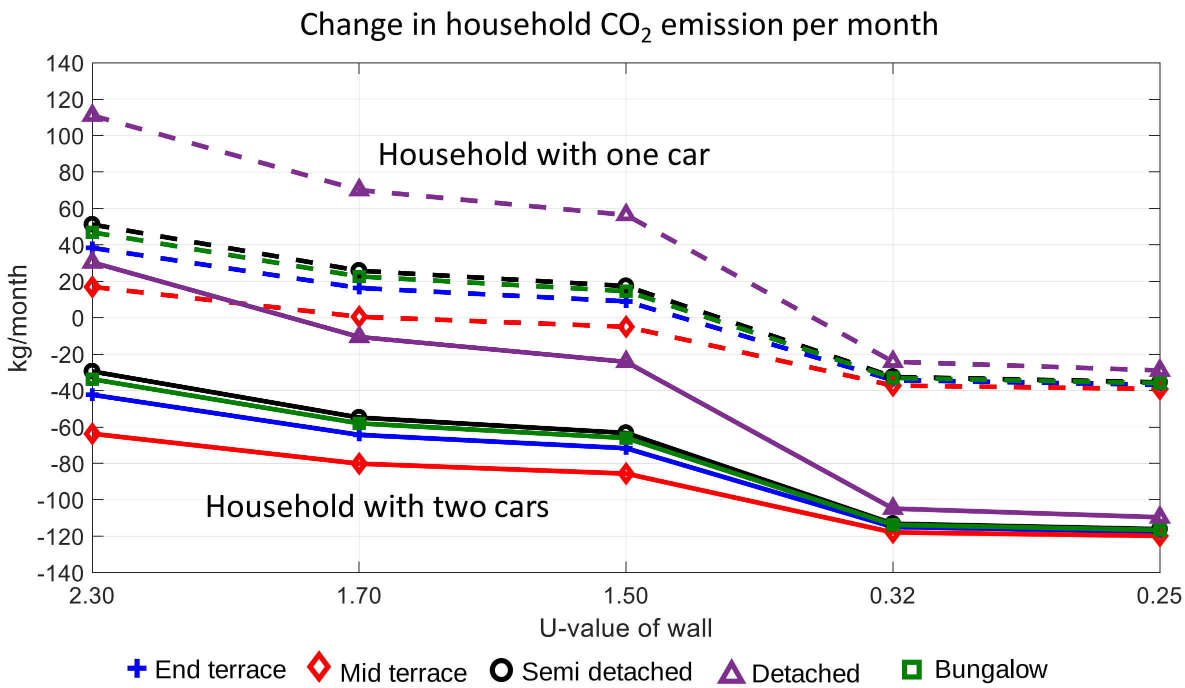

Figure 4: Change in CO_2 emission per month per household based on house type.

lines represent the household using one car. It is found from Figure 4 that households who live in uninsulated buildings with high U-values of wall and use single car for travelling do not contribute to the reduction in net CO_2 emissions; however, households that are in modern insulated buildings with low wall U-values could contribute to the reduction of circa 20-40 kg of CO_2 emission per month if they are using 1 car and 100-120 kg of CO_2 emission per month if they are using 2 cars.

4. CONCLUSION

Working from home due the present Covid-19 pandemic leads to rise in domestic energy demands; however, households in externally insulated buildings with low U-values will not experience significant increase in energy bills. In fact, the reduced travelling by car, or possibly public transportation, will lead to a significant amount of budget savings for those households. The households that do not normally use cars or public transportation, and travel to work by walking or using bicycles, see no travel expenses savings. It is found from the analysis that the rise in domestic heating energy and electricity demand due to working from home would lead to a significant increase in CO_2 emission. However, the reduction in travelling by car will compensate that. Moreover, according to Department for Business Energy & Industrial Strategy [19] the fall in electricity consumption in industrial and commercial sector between March and June 2020 is circa 2457.85 Gwh per month which contributes to a reduction of about 680.83 Mt of CO_2 release per month. Therefore, a complete lockdown situation will result in significant reduction in CO_2 emissions. However, it still effects the household in uninsulated building with increased energy bills. Hence, there is a risk for households who already suffer from energy poverty to have increased energy bills.

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