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Mitigating the impact of climate change on UK buildings through zero energy strategies

Egglestone Kayleigh[1], Abdellatif, Mawada[2], Amoako-Attah Joseph[2], Saif S. AlQuzweeni[3], Khalid Hashim[2,4]

[1] Student Civil Engineering Department, Liverpool John Moores University, Liverpool, UK.
[2] Built Environment and Sustainable technologies (BEST) Research Institute, Liverpool John Moores University, Liverpool, UK.
[3] Civil Engineering Department, University of Babylon, Iraq.
[4] Department of Environmental Engineering, University of Babylon, Babylon, Iraq

Email: K.Egglestone@2018.ljmu.ac.uk

Abstract. It is currently established that one of the paramount concerns in the built environment is the energy efficiency of new and existing UK dwellings, respective to the unfavourable impacts posed to climate change. The Department for Business, Energy and Industrial Strategy in the United Kingdom have reported that the UK's highest recording temperatures have transpired in the years since 2002. With over 90% of England homes currently in use of high carbon systems for space heating and domestic hot water. Contributing to increased atmospheric carbon emissions in the dependency on fossil fuel burning; alluding to human-produced atmospheric temperature increase. To help tackle these issues in the residential sector, the capacity of zero-energy technologies has been introduced. Zero-energy implementation has potential to revolutionise the power system, with on-site power generation at the forefront of this. This paper will explore the influence of zero-energy implementation on two UK residential dwellings of disparate locations, using Integrated Environmental Solutions Virtual Environment (IESVE) by focusing on renewable on-site micro-generation systems. The ASHRAE climate zones of Edinburgh and London Gatwick has been selected to examine the performance of the building over varied regional climates of disparate locations. The selected design variables were finally implemented in combination for building simulation in IESVE and compared with a basic model dwelling. The processed simulation results showed a reduction in the buildings energy consumption of 43.4538MWh (71%) for Edinburgh and 33.9929MWh (64%) for London respective to the baseline model. The greatest savings in mitigation of UK climate change can be evaluated in relation to reduction of carbon emissions, which were 7880kgCO_2 (46%) and 5423kgCO_2 (36%) respectively.

Keywords: Energy efficiency; zero-energy; IESVE; energy consumption; carbon emissions.

1. Background

Evidence of global warming presents the years since 2002 as the UK's highest recording annual temperatures according to the reports of the Department for Business, Energy and Industrial Strategy, UK. With recorded sunlight intensity in 2017, presenting 100% greater than the 1981-2010 average [1]. Addressing anthropogenic atmospheric temperatures from UK domestic energy consumption is vital in mitigation of this to rectifying the potentiality of this magnifying. Governmental decarbonisation objectives hold the authority to the correction of UK climate change, moving forward with legally binding national targets for reduction in carbon emissions. It must be highlighted the climate change is a global problem [2, 3] that causing an unexpected increase in weather temperature [4, 5], uneven distribution of rain [6, 7] and a severe freshwater shortage [8, 9]. This problem (climate change) is a result of several reasons; the first and most imp[ortant reason is the industrial emissions [10, 11], such as the emissions of cement factories [12-14].

These legally binding targets for greenhouse gas (GHG) reduction were approved by the 2008 Climate Change Act, operating through the introduction of carbon budgets. Specifically, with the point of lowering the UK's GHG emissions by 80% by 2050, relative to the 1990 baseline [15]. The Energy Company Obligation (ECO) outlines the importance of household energy efficiency in the achievement of this. It states in its most recent addition, that between 2018-2022, the housing stock is to account for "31% of the UK's total primary energy consumption". This high figure is in accordance with the basic dwelling energy demand requirement in the assurance of substantial thermal comfort for dwelling occupants. According to the Department for Business, Energy and Industrial Strategy, UK; almost 90% of homes in England currently use fossil fuels for heating and hot water, with fossil fuels being a huge contributor to the output of carbon emissions into the atmosphere. This accumulation of carbon emissions from fossil fuels is a key GHG source, driving the heating of the lower layers of the atmosphere and penultimately causing increased temperatures. Therefore, presenting the desirability for alternative energy production, in terms of renewable micro-generation systems, to reduce dependency on natural resources. Thus, mitigating the irreversible consequences of climate change through safe and secure energy resources.

Considering the current attainability of this, the energy efficiency of UK homes are not in the facilitation of this. Evidenced figures present that 66% of total UK homes, around 16 million, have an Energy Performance Certificate (EPC) of D or worse. Department for Business, Energy and Industrial Strategy, UK stated, in 2018, with dwelling band A certificates depicting that of being the most energy-efficient. Therefore, exclaiming a national energy performance inadequacy, working in opposition to the governmental objectives by 2050. Calling for urgency in the retrofit of new and existing homes, with zero-energy strategies as a means of upgrading the EPC and subsequent energy consumption performance of UK homes. Achieving this will ensure the current housing stock is performing in line with national emission targets set by the fourth and fifth carbon budgets. This requires conformity to new and existing rigorous building regulations, along with passive zero-energy considerations in the design stages. The promotion of on-site renewable energy deploys low-carbon techniques to replace fossil fuels, operating towards carbon-neutral dwelling energy systems [16]. Stabilising the reliance upon non-renewable natural resources for dwelling energy production; providing maximised dwelling thermal properties, whilst ensuring occupant comfort. The importance of this is presented in the statistics of UK housing. Hereby, housing demand is increasing consistently per annum, in line with natural population growth. 2019 evidenced the completion of 173,660 newly built dwellings, which is up 20,000 from 2015 figures [17]. This was exclaiming the urgency of sustainable construction to entitle the progression of future housing developments in line with increased population demand; while committed to national carbon emission reductions by 2050

In the context of implementing these zero-energy strategies for low energy homes in the UK, this paper presents the methodology and findings from a dynamic thermal simulation. This simulation process is performed by Integrated Environmental Solutions Virtual Environment (IESVE), considering energy generation and conservation of the residential dwelling before and after micro-generation implementation. Zero-energy modification examples refer to the energy-efficient retrofits which focus on lowering building emittance and energy consumption, specifically solar PV, wind power and heat pumps. Holding analysis to the sensitivity of building performance respective to the regional climates of the disparate UK locations, in terms of dwelling total energy, carbon emissions and total electricity. Providing conclusion to the feasibility of the specified micro-generation measures, in corroborating with national targets for the future successfulness of green building in the mitigation of UK climate change.

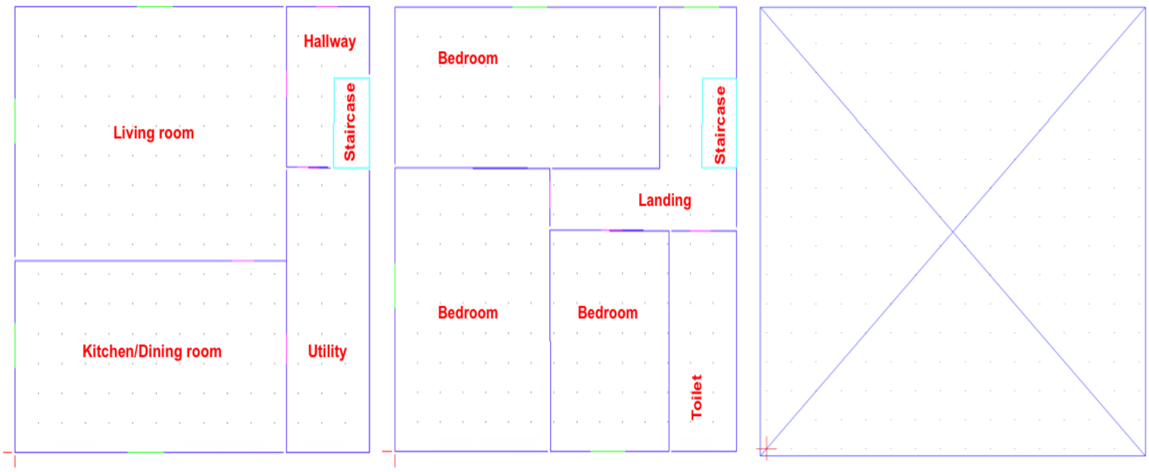
2. Methodology

2.1 IESVE modelling

The data used is the ModelIT two-storey residential-detached building. The building drawings consist of a ground floor plan, first-floor plan and roof arrangement plan. Figs. 1(a)-(c) below indicate the plan of the house used in this work. In the current study, table 1 presents standard construction template U-Values utilised consistently throughout the modelling, in line with the 2013 Building Regulations.

Table 1 Standard construction specifications in IESVE.

	Basic dwelling		Improved dwelling	
	Material	U-Value (W/m^{2}K)	Material	U-Value (W/m^{2}K)
Roof	Uninsulated Roof	2.1442	2013 Roof	0.1800
Door	Wooden Door	2.1944	2013 Door	2.1997
External Window	Small Double Glazed	3.1704	2013 External Window	1.6000
Ground/Exposed floor	Uninsulated Concrete	0.8871	2013 Ground/Exposed floor	0.2200
Internal Ceiling	Timber-Joist	1.2585	2013 Internal Ceiling	1.0866
External Wall	Brick Cavity with Dense Plaster	1.4917	2013 External Wall	0.2599
Internal Partition	2013 Internal Partition	1.7888	2013 Internal Partition	1.6598



(a) Ground floor plan (b) First floor plan (c) Roof arrangement

Figure 1. Architectural plan

2.2 Modelling process

2.11 Baseline model

The baseline model presents a basic dwelling construction template in line with the requirements set by the 2013 Building Regulations. Hereby, there is no implementation of on-site micro-generation systems. This means that the dwelling is solely governed by the building fabric U-Values outlined in table 1, thermal mass, as well as internal and external heat gain. The reliance on a conventional heating system is presented, adopting a gas boiler for central heating using water to heat the dwelling.

2.21 Solar PV

Roof installation of three 'Monocrystalline silicon solar cells' measuring $10m^2$ was presented for both dwellings in London Gatwick and Edinburgh. This PV system is selected in paramount, over a 'Polycrystalline silicon panel' in the achievement of the highest photovoltaic efficiency, with electricity conversion rates said to be higher. Concisely working in the conversion of the sun's energy into available dwelling electricity as an inexhaustible renewable energy source.

2.22 Wind power

The implementation of a small wind turbine was consistently applied over both London Gatwick and Edinburgh. These turbines, which were used in simulations, hold a power rating of 10kW. In the current study, wind power was used to harness kinetic energy to convert into a free and inexhaustible source of dwelling electricity.

2.23 Air-Source heat pump (ASHP)

An electric ASHP was applied to the baseline model for both locations in this processed simulation, reversing the natural flow of heat. This transition from gas to electric heating holds promise to an improved dwelling carbon footprint; attainable due to the refined energy efficiency conversion rate of the ASHP. Specifically selected over the ground-source heat pump due to improved economic viability through reduced initial capital and operation costing.

2.24 Combination of all three design considerations

Hereby all the three respective dwelling zero-energy measures were combined into one concise model and combined with the respective baseline model. This with the point of exploiting solar pv, heat pump and wind energy to improve the building performance for enhanced dwelling energy consumption. Presenting the efficacy of measures in the attainability of decelerated progression of UK climate change.

2.3 Simulation process

IESVE as a dynamic simulation modeller, analyses energy and different building performance workflows. The building performance simulation requires a relevant selection of modelling parameters and assumptions; these have been fulfilled following 2013 Building Regulations and outlined in table 1. The other simulation parameters of occupancy profile and DHW consumption were populated to simulate and reflect true post-construction behaviours. These modelling assumptions can be taken as 5.8l/h (max) for DHW, operating to a consistent occupancy profile shown in figure 2. This is in accordance with the understanding that the dwelling occupants are to be periodically vacated from the dwelling during standard working hours. Most existing buildings in the UK are naturally ventilated, and thus, this was the ventilation strategy implemented in the case of the modelled residential dwelling.

The modelling and simulation parameters of occupancy profile, DHW consumption and internal conditions were kept consistent throughout the process, with the only variant being the weather data used. This is due to the differential weather associated with the Northern location of Edinburgh and the Southern location of London Gatwick. The thermal simulation process is shown in Fig. 3, with its associated modelling parameters outlined in table 1.

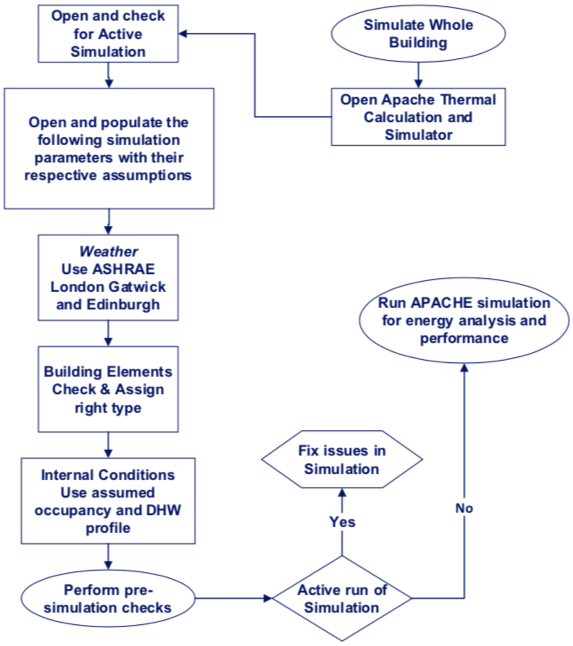


Figure 2. Consistent occupancy profile for the residential dwelling.

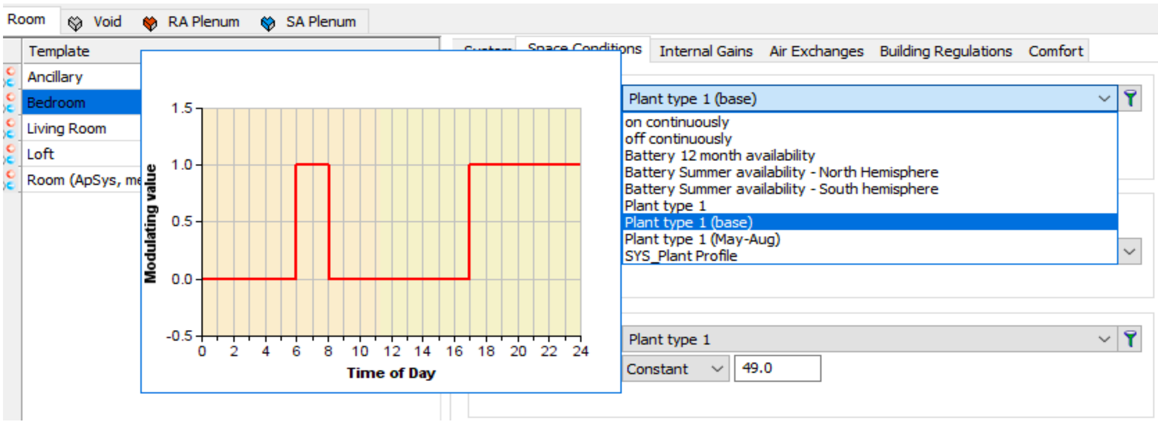


Figure 3. Thermal simulation process.

3. Results and Discussion

3.1 Combination of all three design considerations

The simulation process of the three combined design considerations was carried out by IESVE. The simulation was evaluated in respect to the parameters 'Total Energy', 'Total Carbon Emissions' and 'Total Electricity'. The statistical analysis carried out in figure 4(a-c) suggests the present relation between zero-energy design modifications and improved building performance is established. Figures 4(a)-(c) show comparative statistical analysis to the deviation from the baseline model, after zero-energy implementation at both disparate locations. The general trends consistently evidence disparity in dwelling energy consumption over the three tested parameters, with London persistently of a lower value. This change in consumption yielded is in response to the variation of regional climates at the separate northern and southern sites, as the basic construction and thermal template remain consistent for both. The impressionability of location to dwelling energy performance is presented through the colder northern climate of Edinburgh, to London Gatwick, in closer proximity to the equator. Hereby both dwellings possess variability in energy requirements in the maintenance of comfortable occupant thermal comfort. With lower external temperatures permitting increased energy demand for dwelling space and water heating, possessing adequacy throughout the annum. The annual energy consumption results indicated in figure 4(a), evidence a significant decrease in energy for both locations after zero-energy modification. A declining trend is in respect to the improved dwelling energy efficiency throughout the year, in the presence of on-site energy generation systems. This is attributed to a reduction of 43.4538MWh for Edinburgh, performing 71% more efficiently than the baseline model. Whilst London presents a 64% lower efficiency than Edinburgh, with a total energy reduction of 33.9929MWh throughout the annum comparatively. This improved energy points towards the prosperity of enhanced energy efficiencies and subsequent EPC ratings upon the achievement of net-zero ambitions. Hereby, the renewable house stands paramount when compared to the non-renewable basic dwelling, satisfying lower operational efficiency requirements cohering to government targets. This encourages long-term sustainability in the sector over the estimated service lifespan of the building; whilst amending the depletion of natural resources from dwelling HVAC conditions. Although heat pumps incur a higher capital cost than conventional gas boilers, they can provide increased emission reductions from dwelling heat demand. The dwelling total carbon emissions results indicated in figure 4(b) show an observable decrease in values over both locations, after zero-energy implementation. Unlike the evidenced trend in figure 4(a), the margin of emission deviation from the baseline model is less significant, with extreme value difference less prominent throughout the annum. With both dwellings presenting the lowest emissions in June, exhibited as almost fully carbon-neutral over the months of June-September. This is indicated by an emission decrease from January to June in Edinburgh and London, by 91% and 94% respectively. This can be attributed to the COP of an ASHP being greater in the summer relative to the winter months [18]. The overall annual savings in carbon emissions comparative to the baseline model, can be said to be the greatest in contribution to mitigation of UK climate change. This is evaluated by a reduction of total carbon emissions of 7880kgCO_2 (46%) for Edinburgh and 5423kgCO_2 (36%) for the Southern counterpart. This fall in dwelling emissions gives indication to the potential alleviation to environmental pollution in the replacement of conventional high-carbon and non-renewable dwelling generation systems. Holding authority to this scenario, in providing the greatest offering to government decarbonisation targets, adhering to an 80% reduction relative to the 1990 baseline. Analysis of total electricity in figure 4(c), presents the baseline consumption as almost completely consistent throughout the annum. After full zero-energy implementation, the variability in observed values across both locations is sustained. Hereby, London is evidenced as consuming 1.3677MWh more electricity throughout the annum than the Northern equivalent. This increase can be accredited to characteristic location factors, in the reduced available wind energy and restricted potential return from turbine installation. Edinburgh is located within a mountainous topography, whereby mountains serve as natural towers increasing the distance above sea level for magnified exposure to higher wind speeds. This ensures maximised energy generation for the Edinburgh dwelling, compared to London, which is situated within a more sheltered and low-lying terrain. It can be said that the fall in electricity is consistent with previous trends of seasonal dwelling output, emphasising the efficiency of the systems in the summer months to yield greater electricity cuts. However, this fails to remain consistent for a sufficient duration, holding an incapacity in advocating a year-long enhanced electricity efficiency. Evidenced is a higher overall electricity consumption of 4.9702MWh for Edinburgh and 6.3379MWh for London compared to the baseline model. A potential reason for this could point to the implementation of an electric ASHP, whereby operation relies on

Figure 4. Annual analysis after full zero-energy implementation of both locations.

electricity to move heat from a cool to a warm space. This additional electricity demand is a disadvantage in the installation of ASHPs. Despite the installation of wind and solar electricity generation systems, this still evidences insufficient in offsetting the increased demand. Hereby consideration of the equality of utility costing is emphasised, whereby the well-developed gas networks and cheap natural gas provide a challenge to the acceptance of electric ASHPs.

4. Conclusions

This study empirically quantifies domestic energy, carbon emissions and electricity consumption through simulation of implemented zero-energy strategies respective to a baseline model. Results show that domestic energy consumption differs in different locations and changes appropriate to seasonal variance. This highlighted the influence of location and regional climate on dwelling energy patterns. Generally, it was found that zero-energy efficacy explicitly offered the greatest savings in regards to total energy and total carbon emissions across both Edinburgh and London. As expected, there was a slight increase in dwelling electricity consumption, as the combined simulation held installation to an electric ASHP. However, it should be noted that in line with prospective mass electrification, the inequalities associated with this increased figure are to be minimised. The results of this paper should encourage the acceptance of zero-energy strategies, particularly due to their positive alleviation of environmental pollution through the depreciation of carbon emissions.
Further studies are desirable to better understand the role of zero-energy strategies in developing their markets and policy frameworks to increase public acceptance and education into more extensive national deployment.

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