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Assessing energy use and overheating risk in net zero energy dwellings in UK

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ABSTRACT

This paper presents the methodological approach and findings of a simulation study of advanced energy conservation, generation and management technologies applied to two case study dwellings in the UK, so as to achieve net zero energy (NZE) target that includes a reduction of net regulated energy (HVAC) to 0 kWh/m^2 per year and energy generation of at least 50 kWh/m^2 per year. The performance of the dwellings are also tested for a change in energy use and risk of summertime overheating in future climates in the short (2030s), medium (2050s) and long term (2080s).

The findings indicate that to meet the NZE targets, regulated loads need to reduce by about half (over current Building Regulations) with community (rather than building-level) renewables playing a major role. It is also found that the NZE targets, given current regulations, are not particularly difficult to achieve in design with regard to energy efficiency but are highly expectant with regard to renewable energy. Further, summertime overheating is projected to be a risk for net zero energy dwellings by the 2050s. Despite this the regulated energy use of both dwellings is projected to reduce by 11 kWh/m^2/yr, accompanied by a small increase in renewable generation (2 kWh/m^2/yr).

1. Introduction

Buildings are central to both UK and EU energy efficiency policy. Improving the energy performance of the UK's building stock is crucial, not only to achieve the EU's 2020 targets but also to meet the UK's longer term climate change target of 80% CO_2 emission reduction by 2050. The European Commission [1] outlines three specific targets to be met by 2020 (relative to 1990 levels): reduce greenhouse gas emissions (GHG) by 20%, increase energy efficiency by 20%, and increase contribution from renewable energy sources equivalent to 20% of final energy consumption.

A key element of the Energy Performance in Buildings Directive (EPBD) recast (Directive 2010/31/EU) is its requirements regarding nearly zero-energy building, which is defined as "a building that has very high energy performance..." and its nearly zero or very low amount of energy demand is provided by renewable energy systems, which are either on-site or nearby [2]. Directive 2010/31/EU Article 9 requires that member states shall ensure that by 31 December 2020 all new buildings are nearly zero-energy buildings; and after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy. The EPBD nearly zero energy building definition, as described in Article 2, constitutes a 'broad' definition. The Directive lays down the end-results that must be achieved by every Member State. National authorities have to adapt their laws to meet these goals, but are free to decide how to do so [2].

In the context of implementing these standards for new low energy homes in the UK, this paper presents the methodology and findings from a systematic dynamic thermal simulation study of advanced energy conservation, generation and management technologies applied to two case study dwellings in the UK, so as to achieve a net zero energy (NZE) target. A net zero energy building, in contrast to nearly zero energy, produces enough renewable energy to cover its annual energy consumption [3]. To ensure that design is futureproof, the performance of the dwellings are then tested for change in energy and overheating risk in future climates (2030s, 2050s and 2080s) given that mean external temperatures and solar insolation are expected to increase with a warming climate [4]. This study is part of a Horizon 2020 research project with case studies in Cyprus, France, Italy and the UK, on design, optimisation, implementation and monitoring of advanced and cost-effective solutions for achieving NZE and positive energy dwellings. This paper focusses on the results of the modelling and simulation of

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two case study dwellings (part of a housing development) in the UK so as to satisfy the Directive, by meeting the following NZE targets:

- To achieve a net regulated energy of $\leq 0\,kWh/m^2$ per year. The reduced energy consumption will be attained through the application of a number of innovative energy technologies.
- In order to achieve the NZE target above, at least $50\,kWh/m^2$ renewable energy per year must be generated, on average, in the case study development through either building integrated and/or community renewable energy systems.

2. NZE dwellings and summertime overheating

For over twenty years, NZE buildings have been successfully demonstrated in many countries, including Austria, Egypt, Germany, the UK, and the USA [3]. These buildings have explored exemplar use of miniature cogeneration, high efficiency heat pumps, PV and passive measures like super-insulation, highly reflective surfaces, seasonal pre-conditioning of incoming air via buried pipe.

Research on the subject of NZE buildings has developed significantly to assist in efficient design, efficient monitoring and operation; however the benefit reaches beyond to all buildings whether they are designed to be NZE or not [3]. Until about 15 years ago NZE dwellings were single dwellings built by pioneering developers and architects [5,6], i.e., the NZE drive has largely been focussed on the individual building [7]; however, shared-effort, i.e. dwellings sharing renewable technology to cover energy consumption, has advantages in terms of initial investment costs and energy management [8]. Generally, a set of dwellings, neighbourhoods or communities can support certain technologies for heating, cooling, and electricity generation more cost-effectively through economy of scale. As an example, combined heat and power (CHP) systems are more efficient when a large number of dwellings have to be served. Beyond the typical domestic neighbourhood, mixed-use communities benefit from a mix of occupancies and uses, which can support more efficient use of infrastructure, more space for renewable systems, and more efficient use of energy wherein almost 24-h consumption maximises the use of district heating and power sources [9]. The community level approach is also helpful in achieving an overall cumulative NZE balance where not all buildings are able to meet the NZE target due to individual limitations [10].

Although NZE dwellings are designed to reduce heat losses through improved airtightness and increased insulation, this can potentially raise the risk of overheating and inadequate ventilation [11]. Overheating can occur in such dwellings as a result of a number of causes acting alone or in combination. These can include heat gain from high external temperatures, direct solar gain on the exterior surface or penetrating glazing, and internal heat gains. Home characteristics such as dark surface materials, rooms in the roof, skylights, inability to ventilate due to location, predominately dark hard surface surroundings, single aspect flats on upper floors, and orientation that allows late solar gain in windows can all contribute to overheating [12].

Much research has set out to establish the risk of overheating by simulating the current and future risk in older dwellings [13] and in newer high-performing dwellings [14,15]. A number of studies have also demonstrated present-day monitored overheating or summer 'discomfort' in existing dwellings and newly built dwellings [16] in the UK, and abroad, in Denmark [17], Sweden [18] and Estonia [19]. Within these studies the propensity to overheat is much greater in newer dwellings, e.g. passivhaus designed dwellings, and particularly in flats. It is important to note that overheating is defined slightly differently from region to region, however, there is roughly an agreement that surpassing hours at 26–27 °C is problematic.

A number of studies link overheating in well-insulated buildings with highly important factors being solar radiation [12,15,17,20] and ventilation rate [12,20,21]. In response, highly effective adaptive responses include the following.

- *Shading* [12,22], where the purpose is to limit or exclude incident solar gain on building fabric or entering through glazing. The effectiveness of shading is in design, considering orientation and seasonal changes, and it can be highly flexible; shading can be fixed, manually controlled or automated.
- *High albedo surfacing* [12] of walls and roofs can reduce the heat gain and retention from incident solar radiation; a method commonly used in warmer climates. High albedo surfaces can also be considered for surrounding hardscaped surfaces to further contribute to reduction of the urban heat island effect.
- *Night-time ventilation* [15,21,23] particularly as cross-ventilation [24], where appropriate (lower temperatures and relative humidity), can also be effective in releasing excess heat that is built up and stored in the dwelling during the day. Where night-time ventilation by window opening, shown to be highly effective in cooling the spaces in northern climates, is problematic due to insect, noise, or driving rain, increased mechanical ventilation has been shown to be slightly less effective, albeit acceptable compromise [15].

Though modelling exists to establish effective adaptive responses to the impact of future climate on high-performing/Passivhaus/NZE dwellings, it is also useful to consider findings from research of dwellings built to be high-performing in southern/warmer-climates. In one such study with multiple analogue examples for the UK's future climate(s), Schnieders [25] concludes that the Passivhaus concept is able to provide a comfortable indoor climate, in accordance with EN/ISO 7730 in all twelve locations (including southern Germany, Italy, etc.) exclusively by pre-conditioning with active cooling the supply airflow. It is further explained that external shading in summer, reduction of solar load through opaque elements and minimising internal heat loads are important measures in maintaining thermal comfort. This study uses a simulation based approach to achieve the NZE targets for two dwellings and also examine the risk of summer time overheating in the dwellings, under current and future climates.

3. Methods

Using the well-established suite of Integrated Environmental Solution's Virtual Environment (IES VE) simulation software (dynamic thermal simulation) that include *ModelIT*, *Apache*, *MacroFlo* and *VistaPro*, the expected energy performance of the dwellings and overheating potential are simulated. For comparative purposes five variations of the energy models are created as follows:

1. **Baseline**: the as-designed model;
2. **Reference cases**: reverse modelling of the baseline to establish reference cases:
   a. *Typical reference case*, i.e. consumption of typical existing dwelling in England,
   b. *UK building regulations* reference case: applied building regulations to the model;
3. **Baseline+:** an improved version of the Baseline model to further reduce consumption though established measures;