Are nZEBs nearly near zero enough?

Considerations of nZEB housing and standards as a solution to building associated climate change

OLIVER KINNANE[1] RICHARD O HEGARTY[1] DONAL LENNON[1] SHANE COLCLOUGH[1]

[1]University College Dublin, Dublin, Ireland

ABSTRACT

All new dwellings in the European Union are to abide by the near Zero Energy Building (nZEB) Standard from 2020. Accordance to this standard will result in a much improved next generation of residential buildings, over buildings built even ten years ago. This study, however, investigates if considering the urgent matter of climate change, buildings built to this standard are even efficient enough. Or more pertinently it asks even if we build these new buildings to these high standards, are we building too many buildings? Is there enough of our 'carbon budget' remaining, or might the construction and operation of a new cohort of buildings push us beyond boundary limits? This paper evaluates nZEB in the context of the above narrative. It places nZEB as the optimum build solution for that which will be built and then questions if the nZEB standard is stringent enough. Does it stipulate a performance that is near enough to zero? And can it capture the full range of performance in and across nZEB homes. Are broader or stricter regulations required to ensure these buildings are nearly zero in operation. Or as previously questioned, is building a folly when considered in light of the greater climate crisis context?

The paper outlines a thought experiment based on construction projections until 2060. Phenomena of building usage are identified using some real data from case study buildings of the *nZEB101* project.

1. INTRODUCTION

The answers to the questions are not simple, and boundaries are difficult to clearly define. The solutions also are not clear and certain. In the general field of construction, building science is given relatively little attention. It is caught in a space between the fields of architecture that is disinterested in sustainability and a construction industry that often sees sustainability as a promotional tag. Further the construction industry is a pillar of economic growth in any capitalist society, and as such real change is unlikely as systems and structures remain the same. Even as these systems and structures fail completely to deliver for the basic needs of people, they remain inert. For example in many countries there is an urgent need for housing and this is driving calls for an increase in construction activity and house building. Righting of societal failings in the short term has cause over consideration of long term, less certain, projections. In that case when we do build, however, at the very least we should build with the lowest impact, and to the highest standard of operation. Contemporarily that standard in Europe is the nZEB standard – a standard for 'low' energy operation (but not for low impact construction).

The *nZEB101* project [1] is interrogating nZEB housing in operation, by evaluating a proposed 101 homes, and comparing performance across this set of homes of variable design, construction typology, heating and ventilation methodologies.

Results and data from this project are used in this paper to show the performance benefits of adapting buildings to nZEB. Results, however, also exhibit a wide variability in performance for housing retrofit to the same high standard. These results are used to present the central role of the occupant's personal living habits in shaping the energy usage within the home. The presented results are discussed with reference to retrofit but are also assumed as a proxy for new build to enable discussion of housing in the round. Much is claimed for nZEB, by proponents and players within the energy efficient housing sector. However, to measure the real and relative benefit of nZEB, we must look at the impact of the housing industry as a whole, the possible gains that can result from designing to a higher (nZEB) standard but also the carbon cost of construction activity. Any reductions, or predicted reductions, in carbon intensity deriving from designing to an nZEB standard have to be placed in the context of total housing production – which is rising, housing size – which is rising, building design life – which is falling and the actions of people – which are only ever certainly uncertain.

It is important from the outset to be clear and upfront about the limitations of this study. This paper does not pretend to be a rigorous scientific study of some houses and some data. It is an explorative analysis of the future impact of building even to an nZEB standard. It uses results from other studies to project future possible energy housing related carbon impact. It then evaluates the significance of these in the context of climate change, by evaluating them relative to remaining carbon budgets.

2. CLIMATE, CARBON BUDGETS AND BUIDINGS IN USE

Eminent climate scientists predict imminent risk and call for urgent response. Reduced order, approximation models predict global warming will cross dangerous thresholds as soon as 2036 [2]. A recently released United in Science report by the World Meteorological Organisation predicts current plans would lead to a rise in average global temperatures of between 2.9°C and 3.4°C by 2100, a shift likely to bring catastrophic change across the globe [3]. These are just two examples of the many studies that now abound reporting frightening prospects for climate change. A recent study reported that in worst case scenarios areas currently home to a third of the world's population will be as hot as the hottest parts of the Sahara Desert within 50 years. Even in their most optimistic outlook, 1.2 billion people will fall outside the "climate niche" of human comfort in which humans have lived over the previous 6000 years [4]. Air conditioning usage is expected to grow considerably and is already increasing at an alarming rate globally [5]. The IEA projects that as the rest of the world reaches similar levels of usage to the USA, air conditioning will be associated with about 13% of all electricity worldwide, and produce 2 billion tonnes of CO_2 a year.

Looking further into the climate change science, and particularly the remarkable work of the climate modellers, offers opportunity to put current and possible future building related emissions in an understandable context. Model prediction results from mid-2019 estimate a remaining carbon budget of 480 $GtCO_2e$ for a 50% chance of remaining below 1.5°C, with other models reporting uncertainty bounds that drop the total to as low as $100GtCO_2e$ [6,7]. Numbers in the trillions (giga) of tonnes are difficult to grasp, and a general hinderance to wider understanding of the climate crisis, and in this case construction's association with it. Their impact is lost due to their very scale. In fact, the carbon totals listed in themselves are not particularly insightful, when aiming to understand the impact of buildings. Evaluating with respect of the emissions of the current building stock offers more insight. This paper further looks to the future stock, and assumes an nZEB standard of operation to evaluate performance of the full cohort into the future.

The operation of buildings in existence globally resulted in the release of more than 3 trillion $kgCO_2e$ (or $3GtCO_2e$) in 2018. There was a brief period of decrease in recent years but the total increased again last year, and has generally been on an upward trajectory [8]. This is even though environmental awareness, and cognizance of the factors that cause this high total, have increased in recent years. When direct and indirect emissions from electricity generation and commercial heating are taken into account this number is more than tripled. The International Energy Agency report over 10 trillion $kgCO_2e$ (or $10GtCO_2e$) in 2019 related to buildings, the highest level ever recorded. Although definite proportional breakdown is not easy come by, it is generally assumed that energy/emissions related to buildings are split near evenly between commercial and residential buildings.

Assuming these numbers the impact of running all our buildings in existence today until 2060 equates to $380GtCO_2e$. However, $380GtCO_2e$ does not account for the carbon emissions from the operation (or construction) of new buildings that will be added between now and 2060. The need to ensure all future construction is limited in its impact is obvious. Perhaps even much of construction - which has so often been flippantly undertaken, even celebrated as a boon to national and global economy - should be reconsidered into the future. Housing is one sector of construction that has better credentials of necessity. However, with so many countries in crises of limited supply, and an urgent need to meet demand to house the homeless, considerable increase in house construction is essential.

The need to construct this housing to high standards, ensuring minimal impact in construction and in operation is obvious. The nZEB definition in Ireland is described in the Irish Building regulations as a building that achieves an energy performance coefficient of at most 0.30 and a carbon performance coefficient of at most 0.35 – parameters that refer to improvements in performance over a reference building of last decade's regulations. The original nZEB definition of 2016 for oceanic regions more clearly proposed; 15-30kWh/m^2/yr of net primary energy with, typically, 50-65kWh/m^2/yr of primary energy use covered by 35kWh/m^2/yr of on-site renewable sources [9]. A more strtaight forward definition even (and the one used in this study for simplicity and clarity) [10] proposes a regulated load of 45Wh/m^2/yr with a "significant proportion" to be covered by renewables. This energy consumption profile represents a stringent standard (although no account is taken for embodied energy of construction). By comparison to comply with the Passive House standard, dwellings must consume less than 120 kWh/m^2/yr of primary energy. It also represents a considerable reduction in consumption relative to the current level in homes. In Ireland this is documented as 18,000 kWh/yr for an average home but these can vary in size from average of 171m^2 for a house to 90 m^2, for an apartment (105-200kWh/m^2/yr) [11]. Hence buildings built to a 30kWh/m^2/yr nZEB standard can achieve improvements of up to 84-192kWh/yr over the average, per m^2 of building constructed (when on-site renewables are integrated).

3. CONSTRUCTION AND CONSTRUCTION TO NZEB

Projections for increased global construction are remarkable. Globally it is expected that we will double our current built floor area by 2060 [12].

The following extrapolation uses the referenced values published by the IEA as the basis for calculation of the carbon impact of operation of the buildings that are to be built by 2060. If we assume the same construction growth rate of 2.5% /year to reach that total is maintained, the total amount of carbon that will be added by 2060 will total 572 trillion kgCO_2e. This number is remarkable and concerning as it alone exceeds the remaining carbon budgets for a 50% chance of staying within 1.5°C.

If instead all these buildings are built to an nZEB standard and a value of 45kWh/m^2/yr is assumed, their impact could be reduced to less than 300 trillion kgCO_2e.

The majority of construction growth is expected in developing countries. In Europe - where it is commonly assumed that much of our buildings are built - it is expected that an additional 25 billion m^2 of floor area will be added [3]. Approximately 75% of floor area in the EU27 is residential [13]. Working with these numbers; >18,750 billion m^2 of housing will be developed in Europe alone.

Looking at the Irish context in isolation: the National Development Plan for Ireland outlines plans to construct 550,000 nZEB dwellings by 2040. The carbon intensity of electricity in Ireland is 437gCO_2/kWh [14] - a vast improvement on the carbon intensity of only 15 years ago. There are plans to further decarbonise the electricity supply in Ireland and this will improve the carbon intensity further. However, for the purpose of this thought experiment a value of 437gCO_2/kWh is assumed as static. The addition of a single nZEB, of 130m^2, operating at 45 kWh/m^2/yr would add 2556kgCO_2 /yr. The addition of 550,000 nZEBs will result in an operational impact of approximately 1.4 billion additional kgCO_2e each year of the full cohorts lifetime operation (130m^2 (avg. 171 & 90 m^2)). Appropriating, a value of 1200kWh/m^2, in line with the embodied energy of nZEB dwellings in Ireland calculated by Goggins et al. (2016) [15], the energy required to build all houses would approximate 35.5 billion kgCO_2e.

These Irish numbers alone may seem trivial when thought of in the context of the remaining carbon budget (they are in the low billions after all). However, Ireland is a small country with a small, and aging population.

4. NZEB PERFORMANCE AND PERFORMANCE GAP

Further interrogation of nZEB gives insight into the houses in operation. The *nZEB101* project aims to uncover design and in-use insights of nZEB in operation through extensive monitoring and performance analysis of a large set of nZEBs. The initial study by Colclough et al [16] documented the energy performance of a selection of nZEB housing in Ireland. Case study housing reported an energy load of 52kWh/m^2/yr, with 23% (12 kWh/m^2/yr) of the energy load delivered by renewables. This increases to 54% if the heat pump is assumed as a renewable source of energy, *i.e.* supplied from renewable energy supplies.

In the Irish context the heat pump is a common, although not mandatory, element of the nZEB. It is categorised as a renewable energy source, although the electricity it consumes remains in the majority generated using fossil fuels, including low efficiency peat and coal. In the context of the residences in this study the heat pump accounts for space heating , domestic hot water, and mechanical ventilation system its load is assumed as indicative of the general efficiency of occupant energy usage, although it is recognised that this is a subset of the 'regulated load' only. Figure 1 shows the cumulative energy consumption for an integrated heat pump within 8 nZEB dwellings. Each home is small with floor space 40m^2 and retrofit to the nZEB standard. The data is taken directly from the heat pump unit.

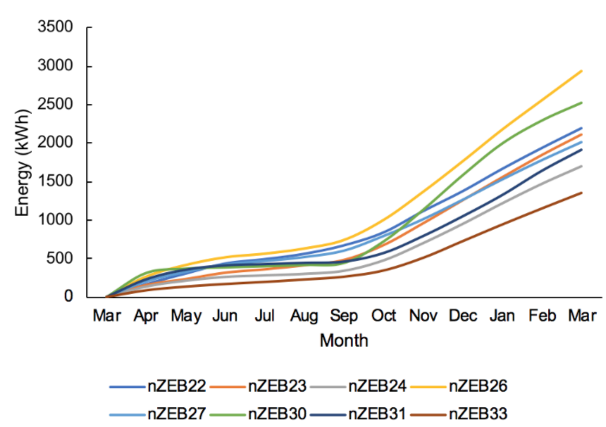

Figure 1. Energy consumption of heat pumps in Irish homes shown as cumulative energy consumption (kWh) against time.

Pertinent to this study, the image shows a wide variation in use performance in these homes. The energy consumption of all homes remain below 800kWh through Spring and Summer but increase considerably during the heating season to reach two and three times that total by end of monitored year (March to March). Two houses in particular – those associated with high internal temperatures – report the highest energy consumption. These results are reported in another paper at this conference by these authors where the actual energy consumption for four of these houses and the internal temperatures are shown to be correlated [17] (*Colclough et al, 'Recorded energy consumption of nZEB dwellings – and corresponding interior temperatures' PLEA 2020*).

Winter data for the same set of houses is shown in shown in Figure 2.

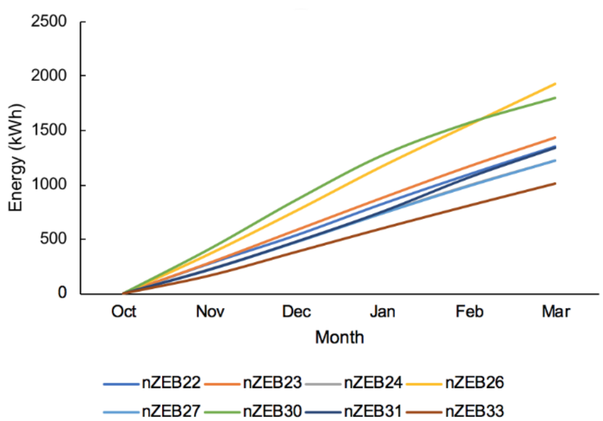

Figure 2. Energy consumption of heat pumps in Irish homes shown as cumulative energy consumption (kWh) against time.

These images show that over the course of a year, or even over the course of a heating period, the variable comfort requirements of occupants result in a widely varying energy consumption. In fact the range of temperatures in which people inhabit in the same climate is remarkable. The interested reader is directed to the other paper by these authors at this conference which reports some remarkable average temperatures for the whole house.

The results are included here as evidence that even in small homes, that receive the same energy efficiency treatment, results can vary widely depending on the living patterns of the occupant.

The corollary to the above results might be assumed to be the same for occupants living in cooling dominant climates. This is particularly concerning in light of the afore mentioned Xu et al study [4] that reports over 1.2 billion people could be living in uncomfortable temperatures by 2060. Certainly some migration flows will result, but if the people who choose to stay, use air conditioning to maintain comfortable temperatures, the impact will be considerable.

5. BETTER, BUT BIGGER AND MORE BOUNTEOUS

This year is the 50th anniversary of the first Earth Day. The number of buildings we have on this planet has grown hugely in that time period. And the energy related to buildings has increased hugely.

To add a positive note to the above narrative there has certainly been a reduction in the amount of energy per m^2 of floor area. Colclough et al 2020 report values that are a considerable improvement on values for housing previously.

There have also been other gains, we have managed to dematerialise quiet successfully. So things including building products contain less natural resources today than they did 50 years ago. And the energy related to the processing of those materials has decreased. Steel and concrete for example can now be produced with about 60% of the energy used in 1970. Steel for example has gone from between 30-40 GJ/tonne in 1970 to < 20GJ/tonne today [18]. Additionally the carbon intensity of our electricity has reduced considerably and that reduces the impact of producing construction materials for building and the operation of buildings itself.

A tonne of cement today produces about 900kg of CO_2. In the early 1970s it was somewhere closer to 1400 kgCO_2 for the same tonne. However, when one works through the numbers as done in this paper it becomes increasingly obvious that these improvement are swamped by other factors that have increased dramatically in that time.

Primarily the population is more than double today what it was on the first Earth Day in 1970. All of those people have required, and continue to require buildings. Not just housing, but also workplaces factories, offices, and increasingly, sports and leisure spaces. Of course with huge variation depending on which country you're born in. However, the key point is that the floor area that we build today has increased hugely.

The seminal text *Growth* [19] by the eminent scholar Vaclav Smil outlines, with reference to national statistics, the huge increase in resource consumption generally, but pertinently for this study built floor area. It has increased by approximately 33% in Europe since the early 1970s. The single-family American house has gone from 150m^2 1970 to over 250m^2 today. And in China the floor area per capita has increased almost 10-fold.

The embodied carbon impact is huge, but even more significant is the operational energy required to run these buildings.

And as people in the developing world demand better standards of comfort like they have in Europe and the US since the early 70s energy related to comfort including space heating and air conditioning as examples are increasing dramatically.

We have much work to do to reduce energy related to buildings. While nZEB is a move in the right direction but it seems that without some curb on the amount of building that we plan to undertake, even these high standards will fail to ensure a sustainable built environment, or avoidance of certain climate change.

5. CONCLUSIONS

This paper evaluates the impact of a reduction in carbon intensity of housing operation through the stipulation of the nZEB standard for new build. Using projection numbers, it also aims to ascertain the overall impact of projected total housing production - even if built to high energy standards - with regard to climate change predictions and particularly so-called 'carbon budgets' to avoid >1.5℃ warming.

With regard to nZEB it is evident that high standards are being set for new housing. Compliance is less obvious, and irrespective of the standard designed to, the occupant can still have considerable impact on final building performance.

The efficiency of housing is improving but the quantity of construction that is projected is swamping all such improvements.

ACKNOWLEDGEMENTS

The *nZEB101* project is supported by the Sustainable Energy Authority of Ireland under Grant Agreement 18/RDD/358.

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