Available online at www.sciencedirect.com
ScienceDirect
Energy Procedia 78 (2015) 687 – 692
Energy Procedia

6th International Building Physics Conference, IBPC 2015

# The role of nearly-Zero Energy Buildings in the definition of Post-Carbon Cities

C. Becchio[a]*, S. P. Corgnati [a], C. Delmastro[a], V. Fabi[a], P. Lombardi[b]

[a]DENERG - Politecnico di Torino, Corso Duca degli Abruzzi 24, Torino 10129, Italy
[b]DIST - Politecnico di Torino, Corso Duca degli Abruzzi 24, Torino 10129, Italy

**Abstract**

Nowadays about 50% of global population lives in cities, responsible for about 70% of GHG emissions and by 2030 the urbanization rate will increase to over 75%.
The paper discusses new emerging concept of "Post-Carbon" City, in which the "vision" consists in the opportunity of breaking the carbon-dependent system of urban areas. It provides inspiration to re-think urban re-development patterns. In this new vision buildings and occupant behaviour role and need for new comprehensive planning tools are investigated. The paper deals with a project that is undergoing study and represents a picture of the current situation related to "Post-Carbon" City topic.

Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL
*Keywords:* post-carbon cities; existing buildings; occupant behaviour; scenarios analysis; energy planning

## 1. Introduction

Nowadays more than 50% of global population lives in cities, responsible for about 70% of GHG emissions and by 2030 it is expected the urbanization rate will increase to over 75%. This process is creating a great pressure on urban areas - resource consumption (energy and land use), air and noise pollution, quality of life, etc. - and changes to be understood and faced at the global, regional and local level.

* Corresponding author. Tel.: +39 011 447 1778; fax: +39 011 090 4499.
*E-mail address:* cristina.becchio@polito.it


Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL
doi:10.1016/j.egypro.2015.11.067

Local governments and decision makers are responsible of the management of public services, land use and transportation, community economy and health and they need of new guidance and support for meeting these critical goals. At the same time, human behaviour is often responsible for unsustainable patterns of consumption at the level of buildings.

The European Commission has created a "Roadmap for moving to a competitive low-carbon economy in 2050" (COM (2011) 112) which involves a cut in the EU greenhouse emissions by 80 percent by 2050 (compared with 1990 levels) entirely through measures taken within Europe [1]. To achieve this, intermediate GHG cuts of 25 percent by 2020, 40 percent by 2030 and 60 percent by 2040 would be needed. This essentially means that the carbon-based society of today which took 200 years to develop would need to radically transform to a new low-carbon society in less than 40 years. In particular, the goal is for annual emissions to be lowered in such a manner so that the increase in global temperature is below 2 degrees Celsius against pre-industrial temperature levels (the industrial revolution occurred between 1750 and 1850).

As one knows, buildings occupy a key place among the major contributors to GHG emissions and have a great potential on energy savings; the reduction of energy demand and the exploitation of renewable sources constitute important measures which are needed to reduce GHG emissions.

Responding to these challenges, the concept of nearly-zero energy building (nZEB) has gained an increasing recognition in literature as it is characterized by very low energy consumption. However, in order to improve further buildings energy performance, measures should take into account not only climatic and local conditions, indoor environmental comfort and cost-effectiveness solution, but also cultural and human factors, such as occupants behaviour.

The paper deals with a project that is undergoing study and represents a picture of the current situation, a sort of literary review of studies related to “Post-Carbon” City topic. In detail, the aim of this paper is to investigate how nZEB can steer toward the new vision of “Post-Carbon” City (PCC), which consists in the opportunity of breaking the carbon-dependent system of urban areas. This original type of city provides inspiration and ideas to re-think urban re-development patterns, leading the way for new comprehensive approaches.

The paper is articulated as follows. The first part introduces the concept of PCC as it emerges from current scientific research projects and reports, including the EU POCACITO project [2]. It also discusses the recent European energy policies toward PCC and the role of retrofit solutions for reducing energy consumption.

The second part of study is focused on the role of buildings and occupant behaviour considering that building performances’ growth is followed by a reduction of energy consumption in which the effect of building physics is decreasing and, on the contrary, the effect of human factors is progressively increasing.

The final part of the paper discusses the opportunity to undertake a long term scenarios analysis for a successful energy planning at urban development level with the aim to achieve post-carbon cities.

## 2. Retrofit solutions for reducing energy consumptions

According to POCACITO project, the concept of “post-carbon cities signifies a rupture in the carbon-dependent urban system, which has lead to high levels of anthropogenic greenhouse gases and the establishment of new types of cities that are low-carbon as well as environmentally, socially and economically sustainable” (http://pocacito.eu/info/what-post-carbon-city).

The European Commission defines the concept as follows: "In a low-carbon society we will live and work in low-energy, low-emission buildings with intelligent heating and cooling systems. We will drive electric and hybrid cars and live in cleaner cities with less air pollution and better public transport" (EU, 2012: Roadmap for moving to a low carbon economy in 2050. http://ec.europa.eu/clima/policies/roadmap/index_en.htm). Transforming Europe's energy system to a low-carbon one has been deemed necessary to address a wide range of existing and expected issues such as combating climate change and the expected depletion of fossil fuels.

The term post-carbon emphasizes the process of transformation, a shift in paradigm, which is necessary to respond to the multiple challenges of climate change, ecosystem degradation, social equity and economic pressures.

Introducing the concept of PCC and its inherent possibility to re-think urban re-development patterns, it’s clear that nowadays the great challenge consists in investing not in fabricating new nZEB but in retrofitting existing buildings towards nZEB. Indeed, while new buildings can be constructed rather easily as nZEBs due to the fact that in construction sector the technological solutions needed for a low-carbon economy are already available, the real cost-effective opportunity for energy and emissions savings is represented by existing buildings retrofitting. Indeed, since approximately 40% of Europe's building stock predates the 1960s, it is predominantly characterized by very poor energy performances and consequently in compelling need of renovation. Unlike emerging economies such as China and India that are experiencing an explosion of new building, new construction in Europe represents only about 1% of building stock and renovation rates are low, standing at approximately 1% of edifices; most buildings present today in the EU will still be standing in 2050. EU energy efficiency laws for buildings are some of the world's most progressive, but implementation is patchy and varies by country. Full execution of existing regulation is needed to promote both energy-efficient new builds and retrofits, the latter being where most savings can be achieved.

Therefore, the existing buildings retrofit with its significant potential for both cost-effective $CO_2$ emissions mitigation and substantial energy consumption reduction can be seen as Europe's biggest energy resource playing a crucial role in hitting 2050 targets. According to European Commission the minimum energy savings in buildings can generate a reduction of 60-80 Mtoe/year in final energy consumption by 2020. Nevertheless, it remains unclear which concrete actions, legislative measures and financial instruments are necessary at the EU level to reach these long-term targets. Indeed, achieving the energy and emissions savings in buildings with the application of retrofit actions is a complex process. In order to help policy makers to determine the appropriate way forward, different studies at European and national level have been fostered. Fraunhofer Institute and partners show that, by implementing energy savings measures, fuel-use in the EU built environment can be reduced by 22% (2020) and by 46% (2030) compared to 2005 [3]. Ecofys et al. shows that GHG emissions can even be reduced by 44% (2020) and 60% (2030) compared to 2005, when full energy savings are applied in conjunction with renewable energies [4]. BPIE survey describes a number of possible scenarios for the renovation of the EU building stock by 2050 [5]**Errore. L'origine riferimento non è stata trovata.**. In detail, BPIE model was used to create different scenarios that combine depths renovation pathway (shallow, intermediate, deep and two-stage) and various rates of renovation (slow, medium and fast). Analyzing the results of the different scenarios only two (the deep and the two-stage scenario) achieve the ambitious European $CO_2$ reduction targets (of around 90%) as described by the European Commission in its Roadmap 2050 paper, but only under the assumption that the power supply sector undergoes a fast decarbonisation as well. In both these scenarios, since 2015 deep and nZEB renovation become the dominant activity, while both minor and moderate retrofit measures account for just 5% of the total. The term "minor" renovation indicates a single energy efficiency measure, such as a new boiler plant or the thermal insulation of the roof space. Typically, the application of three of these minor EEMs is associated to a 30% of an energy saving and they are characterized by low investment costs. At the other end of the scale, renovation can involve the wholesale replacement or upgrade of all elements which have an influence on energy use, as well as the installation of renewable energy technologies in order to reduce energy consumption and carbon emission levels to close to zero, or, in the case of an energy positive building, to less than zero. The hypothesis of BPIE study is that the reduction of the energy needs towards very low energy levels will lead to the avoidance of a traditional heating system. This is considered to be a break point where the ratio of the benefits, in terms of energy cost savings, to investment costs reaches a maximum. This depth of renovation identifies an nZEB. In between these two renovations levels there are some intermediate ones. These can be subdivided into "moderate", involving three - five energy efficiency measures, and "deep". A deep renovation typically adopts a holistic approach, viewing the renovation as a package of measures working together, but its definition represents a problem because there is currently no commonly agreed definition of the term. Deep renovation is defined differently from country to country; often it is referred to percentage reductions in energy use, but they can also refer to reaching an A category under the Energy Performance. Nowadays, only a minority of upgrades is substantial or what experts refer to as deep renovation. Encouraging deep and nZEB renovations through clear legislation and innovative financing mechanisms would help achieve scale and help meet the 2050 targets.

At the same time, measures to increase energy efficiency in buildings support several other important societal and individual goals, such as increased employment and an enhance to economic activity, improved quality of life, reduction of fuel poverty and better security of supply with its lower dependence on imported fossil fuels. The goal should be to create a high-performance existing building by applying an integrated whole-building design process. For example, the integrated project team may discover a single design strategy that will meet multiple design objectives. Doing so will mean that the building will be less costly to operate, will increase in value, last longer, and contribute to a better, healthier, more comfortable environment for people in which to live and work. Improving indoor environmental quality, decreasing moisture penetration, and reducing mold all will result in improved occupant health and productivity. This makes energy policies in building sector a highly multi-purpose tool to achieve numerous important targets.

## 3. The impact of occupant behaviour on building energy consumption

Since the success of an nZEB depends on how the building is designed, built, and actually managed, occupant comfort and behaviour can have a significant impact on the energy performance. Individual occupants and the choices they make (opening and closing windows, turning up and down the thermostats, etc.) directly affect the amount of energy used in every type of building. The building occupants enjoy an improved sense of health and well-being that can be attributed to improved daylighting, quality high-efficiency lighting, and better indoor air. Without occupants' support of a building's high-performance attributes, even the most well designed building can fail to measure up to its high-performance potential. Research shows that if occupants do not act in a way that supports design intent, performance standards can be compromised. Many studies show how different occupants' behaviours affect energy consumption in buildings by analysing variations in the energy usage between identical houses with different occupants. Starting with Solocow [6], who found differences in energy usage of more than a factor of two in identical houses, many researchers have focused on comparing energy consumptions of similar houses [7,8]. Among them two of the latest studies showed dramatic variations: Andersen [9] found that the energy consumptions of 290 Danish dwellings varied by up to a factor of 20 (from 10 to 200 kWh/m²); and Meier et al. [10], analyzing 22 identical houses in Germany, discovered that the maximum gap in energy consumption was of 284%. Branco et al. [11] noted that the real energy use was 50% higher than the estimated energy use (246 MJ/m² as opposed to 160 MJ/m²) in an experimental study conducted over 3 years in multifamily buildings in Switzerland. The aforementioned studies highlighted that the differences between real and predicted energy use depends on both the final realisation of the construction, the technical installations, and the real use of the built systems operated by occupants. Although occupants are critical to the success of a high-performing building, they are often the missing piece of the sustainability puzzle because of the complexity in addressing human behaviour. To face this topic, different assumptions to model the occupants' window-opening behaviour are made in literature. For instance, schedule regarding window opening are usually based on occupancy or on the expectation that window opening to be controlled by temperatures, humidity, wind, rain or to produce an established airflow rate, supposing the occupants use the windows to achieve the design ventilation rates [12]. These assumptions do not necessarily represent the occupants' actual behaviour and for this reason, it is necessary to use algorithms for users interactions with the building control systems based on field investigations in real buildings.

With this purpose, a simulation study on the effects of occupant interactions with windows and the heating control on energy demands has been conducted in a typical dwelling of a residential high performing building was carried on by Fabi et al. [13]. In this paper, a high performing building has been chosen as case study for the evaluation of energy performances. The probability of opening and closing the windows and switching up/down the set-point temperature on the TRV has been predicted for different users models for window opening and for heating set-point preferences. Results of the study highlight significant influences of occupant behaviour on the building energy demands raising up to 36% in comparison to the high performing building where the occupants' interaction with the controls is regulated by fixed schedules.

## 4. Scenarios analysis for a successful energy planning

As mentioned in the previous paragraphs, the ambitious targets set by European Commission in the direction of a low-carbon society, such as the case of nZEB, requires the investigation of appropriate strategies to achieve the desired goals over the fixed time-horizon. Different mid/long-term scenarios are the only opportunity to produce indications about the future and to support decision making in the choice between different policies. Despite the difficulties connected to unpredictable changes, the effectiveness of energy policies could be evaluated by taking into account that it is composed by two main aspects: a direct impact factor, "deterministic" and strictly correlated to an extrapolation of past effects, technological and other changes and an indirect uncertain factor linked to the users perception and reaction to the different measures, and consequently to the different occupant profiles and their socio-economic conditions. Including this second "stochastic" aspect in the analysis is a real challenge to cover the gap between forecasted results and reality and to release predictions as accurate as possible.

Anyhow, in order to evaluate the role of nZEB in the direction of PCC it is not sufficient to perform scenarios analysis on the building sector only, but it its impact on the whole dynamic energy system and the interaction between the different subsectors - residential, industry, transportation and services - should be considered. Energy demand forecasting models are suitable quantitative tools for an energy-oriented city planning. They start from a simplified, but adequate, description of the reality and provide a realistic comprehensive approach to reproduce urban transformations. The energy systems' structure and flows are graphically represented through the Reference Energy System (RES) in which the links between the different commodities flows are described, for all sectors and activities, by involving the energy chain from final use to extraction and by considering existing and future technologies characterization [14].

Both the theoretical background and the type of approach split energy forecasting models into two main families: top-down (macroeconomic) and bottom-up (process-oriented). The top-down approach has been developed in the '50s to make decisions about future energy supply in order to meet the rising energy demand of the OECD (Organisation for Economic Co-operation and Development) countries [15]. These models are based on macro-economic theory and have been adopted by municipalities and economists for the evaluation of environmental and economic effects/costs of policy measures [16,17]. The second type has been greatly diffused since the '70s on the needs of understating energy demand trends to define energy policies after the oil crisis. Bottom-up models are disaggregated partial equilibrium models, engineering-based and characterized by a rich technological description; they have been predominantly used for deriving the lowest cost opportunity to reach a fixed efficiency level or GHG reduction [18,19]. The different focus of bottom-up and top-down models leads to differentiate their field of applications and indicate different perspectives of forecasting and policy strategy choices.

Additionally, with the improvement of computational tools, it is possible to archive and transfer data and results to Georeferenced Information System (GIS) tools [20] and to set Urban Energy Maps with 4D interfaces providing an overview of the time evolution of the stock and main results (energetic and environmental); moreover, it aids to easily identify criticalities, to support advanced energy planning and to disseminate the output of the analysis.

Besides consideration on the structure and the approach, both models types require a detailed set of input data that highly affects the reliability of the models results. To solve data constrains, on one side, the enrichment of the quality/quantity/reliability of input data, the development of representative databases and the identification of Key Performance Indicators (KPI) to benchmark different realities are necessary. On the other side, even if data are available, it is fundamental to promote Advanced Input Modelling (AIM) procedures to deepen the analysis on service demands evaluation, by including the previously mentioned "stochastic" humans-related variables. This aspect is particularly interesting, since from an inaccurate representation energy system could derive a negative impact on measure recommendations and consequently on resource allocation.

## 5. Conclusions

This paper has investigated the role of nZEB within the new vision of Post Carbon Cities, a sort of literary review deals with two concepts. In particular, since 40% of Europe's building stock predates the 1960s and it is in compelling need of renovation, the paper has discussed the great challenge not in fabricating new nZEB, but in retrofitting existing buildings towards nZEB. Encouraging deep and nZEB renovations through clear legislation and innovative financing mechanisms would help meet the 2050 targets and to contribute to a better, healthier, more comfortable environment for people in which to live and work.

Anyhow, since the success of an nZEB depends not only on how the building is designed and built, the paper explains another important pole in the transitions paths toward Post-Carbon communities, the importance of the choices made by individual occupants (opening and closing windows etc.). Research shows that if occupants do not act in a way that supports design intent, performance standards can be compromised with impacts that can be raised up to 36%.

Nevertheless, it remains unclear which concrete actions are necessary to engage a real shift towards the proposed goals. The analysis of different mid/long-term scenarios performed through quantitative energy demand forecasting tools - concerning not only the building sector, but the whole energy system - are the only opportunity to produce indications for an energy-oriented city planning. After a brief explanation on the main energy models families, the research study focuses on the problem of data constraints that highly affects the reliability of models results. This issue highlights the necessity Advanced Input Modelling procedures to improve the effectiveness of measure recommendations derived through scenarios analysis.

## References

[1] European Commission. A Roadmap for moving to a competitive low carbon economy in 2050. COM(2011) 112. Brussels: Belgium; 2011.
[2] EU POCACITO project Web Site. Available online: http://pocacito.eu/info/what-post-carbon-city
[3] Fraunhofer-Institute for Systems and Innovation Research (Fraunhofer ISI) and partners. Study on the Energy Savings Potentials in EU Member States, Candidate Countries and EEA Countries, Final Report for the European Commission Directorate-General Energy and Transport; 2009.
[4] Ecofys. Sectoral Emission Reduction Potentials and Economic Costs for Climate Change (SERPEC-CC), Summary report; 2009.
[5] Building Performance Institute Europe (BPIE). Europe's building under the microscope. Brussels; 2011.
[6] R.H. Solocow. Saving Energy in the Home: Princeton's Experiments at Twin Rivers. Cambridge: Ballinger Press;1978.
[7] G.J. Levermore. Monitoring and targeting; motivation and training. In: Sherratt A.F.C. Energy Management experience Conference. CICC. Cambridge; 1985. P. 21-30.
[8] A.S. Bahaj, P.A.B. James. Urban energy generation: the added value of photovoltaics in social housing. Renewable and Sustainable Energy Reviews 2007; 11:2121-2136.
[9] R.V. Andersen. The influence of occupants' behaviour on energy consumption investigated in 290 identical dwellings and 35 apartments. Proceedings of the 10th International Conference of Healthy Buildings, 8-12 July, 2012, Brisbane, Australia.
[10] A. Meier, C. Aragon, B. Hurwitz, D. Mujumdar, D. Peffer, M. Pritoni. How people actually use thermostat; 2009.
[11] G. Branco, B. Lachal, P. Gallinelli, W. Weber. Predicted versus observed heat consumption of a low Energy multifamily complex in Switzerland based on long-term experimental data. Energy and Buildings 2004;36: 543-555.
[12] Rijal HB, Tuohy P, Humphreys MA, Nicol JF. Using results from field surveys to predict the effect of open windows on thermal comfort and energy use in buildings. Energy and Buildings 2007;39: 823-836.
[13] Fabi V, D'Oca S, Buso T, Corgnati SP. The influence of occupant's behaviour in a high performing building. Proceedings of Climamed 13 Conference, 3rd-4th October 2013, Istanbul, Turkey.
[14] Hoffman K, Wood DO. Energy system modelling and forecasting. Annual Review of Energy 1976;1:423-53.
[15] Herbst A, Toro F, Reitze F, Jochem E. Introduction to Energy Systems Modelling. Swiss Journal of Economics and Statistics 2012;148:111-135.
[16] Haurie A, Labriet M, Loulou R, Kanudia A, OPEC Oil Pricing Strategies in a Climate Regime: a Two-Level Optimization Approach in an Integrated Assessment Model. 2008; http://www.iea-etsap.org/web/applicationGlobal.asp (last accessed 02/02/2015).
[17] AEA Energy & Environment. Review and update of UK abatement costs curves for the industrial, domestic and non-domestic sectors. ED43333- Final report (Issue 3) 2008; http://www.theccc.org.uk/wp-content/uploads/2008/12 (last accessed 02/02/2015).
[18] Eboli F, Parrado R, Roson R. Climate-change feedback on economic growth: explorations with a dynamic general equilibrium model. Environment and Development Economics 2010;15:515- 533.
[19] Capros P, Paroussos ., Fragkos P, Tsani S, Boitier B, Wagner F, Busch S, Resch G, Blesl M, Bollen J. Description of models and scenarios used to assess European decarbonisation pathways. Energy Strategy Reviews 2014;2: 220-230.
[20] Fonseca JA, Schlueter A. Integrated Model for characterization of spatiotemporal building energy consumption patterns in neighborhoods and city district. Applied Energy 2015;142:247-265.