Roadmap Toward NZEBs in Quito

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Abstract. Equatorial and Andean climate has no extreme temperatures; however, the region has a high diurnal oscillation. The government seeks to contribute to the improvement of housing conditions, which is mainly reflected in the emblematic housing program “Plan Casa para Todos” (PCT). PCT that aims to cover the social demand and reduce the qualitative housing deficit. It has been widely discussed that habitability and the housing deficit cannot be improved if the thermal conditions of dwellings and passive designed strategies are ignored, thus passive design principles, active devices, and renewable energy (RE) offer a way forward. Based on the hypothesis to bring out the possibility of reaching Net-Zero Energy Buildings (NZEB) in Quito, the objective is to develop a roadmap towards possible NZEBs. Inspired by genetic algorithms, optimization models were used to obtain the ideal NZEB for Quito. Simulations were carried using Python software with the calculating engine Energy Plus. First results show that the relationship towards the urban grid, the internal and spatial layout, thickness of walls, roof’s sealing, among other factors, significantly affect the energy-efficiency as well as the thermal comfort conditions. Further research is required from the science-policy interface to apply NZEBs effectively.

1. Introduction
Global welfare depends on the collaboration of all sectors and regions of the world, which are established in the objectives of different pacts, like the Paris Agreement, the Marrakesh Agreement, and the 17 Sustainable Development Goals. All those coincide on decreasing the Greenhouse Gas (GHG) emissions in the next decades to come. Andean cities have engaged in the promotion of well-being, counting cities like, Bogotá, Quito, La Paz, Sucre, and Santiago are reporting the highest GHG emissions for their countries [1]. A significant part of their emissions originate within the construction sector, consuming about 39% of all the produced energy [2]. This challenge represents, on the other hand, an opportunity among several disciplines where architects and engineers have a positive and direct impact on the change process. In this regard, Net-Zero Energy Building (NZEB) offer a window of opportunity towards an annual value of zero energy consumptions. Countries with four seasons have developed that idea, also considering the indoor comfort of its inhabitants. Countries in the central Andean region, on the tropics and 2800 masl, without limited seasonality changes, nor extreme temperature ranges in diurnal oscillation, challenges towards NZEBs are rather focused on how to implement an NZEB in non-industrialized countries.

1.1. Objective
The purpose of this study is to assemble a roadmap that leads the city of Quito towards the mitigation of GHG through NZEBs. Therefore, it is necessary to identify their added value in climatic terms as well as to justify why their implementation in Quito would contribute to a reduction in GHG emissions.
Additionally, and based on the case study, it is considered a priority to highlight regional conditionality and set research precedents that address potential obstacles toward NZEBs.

1.2. Justification
As a signatory of the Paris Agreement, Ecuador is committed to the decrease of GHG emissions to less than 40 Gigatons by 2025 thus, contributing to limiting the global forecasted 2°C temperature increase [3]. By 2011, Quito reported 5.17 million CO2eq/tonnes per year and 5.76 million CO2eq/t by 2015. Average, 52% were produced by the transportation sector, 35% by the inherent energy consumption in the residential sector and 13% were produced by solid waste material [4] [5]. Noticeably, the opportunity for emission reduction relates to the fields of architecture, engineering, and the building sector (AEC). Interestingly, the link between transport and the building sector is complemented by the use of electric vehicles (EV) [6] as these have been considered among the multiple criteria of NZEBs.

2. NZERO definitions
In general terms, a net-zero energy building (NZEB) is the one that equals the annual consumed and produced energy to zero [2]. As a concept, the definition of NZEB has been developed ambiguously by some authors [7] [8]. Also, there is a definition of nearly-zero Buildings (nZEB) given by the European Standards [9]. More rigorous NZEBs’ definitions are in the study of Wells et al. [7] who identified five generations of this type of buildings, regarding the evolution of zero energy buildings throughout time (see Table 1). About NZEBs in Quito, currently there are some buildings with a LEED certification, but none of them reach a net-zero consumption of energy. This paper considers a typical residential building of Quito and unfolds on a set of criteria and strategies towards a hypothetical fourth generation NZEBs. It is assumed that Quito could reach such goal as no great investment in heating or cooling systems would be necessary.

| Characteristics of Buildings                                      | 1G: Green buildings | 2G: nZEB | 3G: NZEB | 4G: NZEB | 5G: Future generations |
|------------------------------------------------------------------|---------------------|---------|---------|---------|-----------------------|
| Energy efficiency usage                                         | ✔                   | ✔       | ✔       | ✔       | ✔                     |
| Consideration of impacts on the natural environment             | ✔                   | ✔       | ✔       | ✔       | ✔                     |
| Policy support                                                   | ✔                   | ✔       | ✔       | ✔       | ✔                     |
| Energy balance usage                                            | ✔                   | ✔       | ✔       | ✔       | ✔                     |
| Consideration of electric vehicles charging station             |                     |         |         |         |                       |
| Economic viability                                              | ✔                   | ✔       | ✔       | ✔       |                       |
| Consideration of climate change                                 |                     |         |         | ✔       |                       |
| On-site energy storage and ‘smart’ technology                   |                     |         | ✔       | ✔       |                       |
| Embodied energy (renewable technology infrastructure) [10]       |                     | ✔       | ✔       | ✔       |                       |
| Regenerative building creating a sharing economy                 |                     | ✔       | ✔       | ✔       |                       |
| NetZero Energy districts                                         |                     | ✔       | ✔       | ✔       |                       |
| Positive energy balance usage                                   |                     | ✔       | ✔       | ✔       |                       |

3. Methodology and Simulation
3.1. Case Study
Quito is located at 2812 masl, latitude -0.15, longitude -78.48 in time zone 5 with average temperature 16 °C. By 2020 it will be the most populated city in the country with a population growth projection of 2'781.641 [11] and a density projection of about 53 people/ha to 2025 [20]. The 73.38% of its population belongs to the low-middle and middle socio-economic class [12]. People inhabit with a certain thermal discomfort, especially at night, they do not use heating systems, probably these do not reflect a positive cost-benefit relationship [13]. Nevertheless, one requirement we pretend to reach is the well-being of
residential users, as well as to contribute to a reduction of urban GHG emissions [5]. Also, the fundamental requirements that residential buildings must accomplish are defined in codes like NEC-HS-EE, ASHRAE-90 and EN 16798-1.

Quito’s residential uses are characterized by lacking any insulation concepts and being as of reinforced concrete structures, and formal or informal constructions with masonry made out of concrete blocks and the majority of three floors [14]. The sector AEC offers single-family houses of one and two floors, and residential towers with an average height of ten floors [15]. It has been established, first to analyses urban housing development of Quito and multiple housing projects, including the project launched by the government of Ecuador “Casa para todos”, in which thousands of low-income houses are being built with characteristics bounded in the Metropolitan Ordinance 172 of Quito [16].

3.2. Methodology

Four representative types of dwellings were chosen for the simulation: a townhouse residential-mixed 3-floor building, an isolated 10-floor apartment building, and an isolated single-family house of one and two floors. Two theoretical prototypes were simulated in Quito, for each typology chosen, with (Insulation Construction System=I) and without (Traditional=T) thermal insulation (See Table 2). The I system considers many criteria about Passive house concepts [17] [18] [19]. For the simulation of the T, we worked with a reinforced concrete structure, flat slab and lightened block walls (1*). Currently (2019) Ecuador does not have commercial catalogues of insulating construction systems, the catalogue of insulating materials in Spain was taken as a reference. First, it was analyzed a typical building, and then that was improved using insulation with a ventilation system and photovoltaic panels for the generation site-energy. For the simulation of buildings with I were used: a double leaf facade, 4 cm insulation, double glass (2*); and ventilated facade, insulating glass (3*).

3.3. Simulation

The simulation engine was EnergyPlus program [20], and the data entry was made through the SketchUp graphical interface with SG Save and Open Studio plug-ins. The optimization was carried out through Python with codes of genetic algorithms. The control data for energy optimization inside the home are: dry bulb air temperature 18 °C > T dba < 26 °C, relative humidity 40% > H rel < 70%, values estimated as optimal in ASHRAE 55 and studies of thermal comfort in Quito [21] [22].

4. Results and Discussion

The simulation results show that, for Quito city, the use of passive house design-concepts, passive solar heat gains, thermal insulation according to the climate, and high compactness, help the house not to present a demand for heating or cooling (See Table 2). The use of small overhangs (0.15-0.3m) in the windows of the north facade limits the overheating in summer. Minimal increases in openings in the south facade (an additional 1 to 5% in comparison to the other facades) generate sufficient solar heat gains, even in the winter.

| Type                  | Mixed Use | Block of flats | Single-family | Single-family |
|-----------------------|-----------|----------------|---------------|---------------|
| Type                  | T         | I              | T             | I             |
| Construction System   | 1*        | 2*             | 1*            | 2*            |
| No. Floors            | 3         | 3              | 10            | 10            |
| Gross area (m2)       | 168       | 168            | 6300          | 6300          |
| Cold discomfort (kWh·year) | 4469   | 553            | 9658          | 0             |
| Heat discomfort (kWh·year) | 0      | 2572           | 0             | 1953          |
| Facade hollow (%)     | 30        | 23             | 40            | 23            |
| Compactness           | 1.11      | 1.11           | 3.31          | 3.31          |

Table 2. Summary of simulated buildings and partial results
It is necessary to solve the energy supply to EV to achieve an NZEB 4G. An analysis of the average energy expenditure was carried out on combustion vehicles and EVs [23] [24]. The performance of RE proved to be sufficient for energy demand (without considering EV) in 3 out of the 4 simulated prototypes with a surplus between 30-40%. Said surplus does not replace all the energy needed for the current annual demand (21600km / year) for EV power, this could be solved with the future increase of VE charging stations or a decrease in the use of the vehicle per year, by improving services and capacity of sustainable public transport. Thus, reducing not only the use of vehicles but also CO2 emissions (See Figure 1). Generating an NZEB 4G is possible in the near future for Quito.

![Figure 1](image)

Figure 1. Annual comparative of consumption and on-site generation of energy at homes in Quito.

5. Roadmap
Figure 2 shows a potential roadmap towards an NZEB in Quito. The graph shows three phases divided in the short, medium and long term.

5.1. Short-term Milestones:
- Shared vision: All sectors from politicians, academics, industry, to population need to share awareness about global warming, and to lead efforts toward researches that arrive in NZEBs.
- Research indoor air quality (IAQ): Considering that Quito does not have critical temperatures and the purchasing power of the citizen of Quito is low; it is necessary to state appropriate parameters for Passive house starting from Outdoor Air Quality and IAQ exchange.
- Research on vernacular architecture: To achieve inexpensive passive houses it is indispensable to study ancient local strategies and materials that may contribute to the comfort of people in similar geographical conditions.
- Prototype: Obtain optimal and efficient systems for different house types require a deep assay of the different ideas from the previous investigations.
- Introducing high-tech solutions: Use systems like artificial intelligence controls or photovoltaic panels are essential to get effective NZEBs. Decrease costs for using high-tech approaches could occur with stakeholders’ incentives to researches and local production of those.

5.1.2. Middle-term Milestones:
- Low-tech NZEB industrial infrastructure: Consolidate construction technologies toward an NZEB need to involve all the stakeholders including politicians.
- Modelling tools: The design of NZEB, require computational modelling. There are different software and there are minimum parameters in local codes (NEC-HS-EE). Interested parties, developers and the academy should provide parameters that facilitate the designs.
- Standardize NZEB: NZEBs goal should be defined. Because of the climate advantages of the city, probably a 4G NZEB should be pursued and understood as a feasible goal.
- NZEB Politics: Law, codes, and norms have to encourage the implementation of NZEBs with incentives, and state penalties. They must be focused on new buildings and sustainable retrofitting of existent ones. Furthermore, these laws should promote the vertical expansion of the city to avoid occupying green rural areas.

5.1.3. Long-term Milestones:
- Setup carbon footprint database for building and positive learning cycles: Establish feedback mechanisms that contribute to the improvement of codes, provide information to further research as well as to the overall civil society.
- High-Tech NZEB industrial infrastructure: Go further to establish efficient 4G and later 5G buildings would require to decrease costs of high-tech NZEBs. Developing or co-developing the necessary technology with installed national capacities.
- Smart and decarbonizes grids: In a final stage it is crucial to get plus energy buildings, net-energy districts and regenerative building creating a sharing economy.

6. Conclusions
After a bibliographic review and computer modelling of typical buildings in Quito, it is clear that it is crucial to develop thresholds about Passive House and NZEB for this region. Because of in the Central Andes there is a non-critical climate, but other obstacles to get robust energy efficiency buildings, like the low purchase power of the citizen. First results show that the relationship towards the urban grid, the internal and spatial layout, thickness of walls, roof’s sealing, among other factors, significantly affect the energy-efficiency as well as the thermal comfort conditions.

Although a multi-familiar block did not supply all its energy demand with renewable energy (RE), its large volume of thermal mass provides more thermal inertia against temperature fluctuations than smaller scale buildings. To reduce CO2 emissions, it is also important to generate sustainable urban development, limit horizontal urban expansion to the rural area, promote vertical growth, and reuse existing urban infrastructure, to avoid high demands on energy resources and an abrupt anthropogenic impact on the environment ambient.

It is preferable to establish high goals from the beginning, to avoid that people could see auto-sustainable houses like an opportunity of wasting more energy that they really would have. NZEBs need high-tech, but those are expensive in a nonindustrialized country. Therefore, all stakeholders need to invest in investigations to produce national technology, and so, reach efficient and accessible buildings. Further research is required from the science-policy interface to apply NZEBs effectively.
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