Clarifying Net Energy Positive Design

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ABSTRACT: Over the past decade, numerous building projects have been presented as "net zero" energy or carbon "neutral." Such claims have been made through using a variety of different approaches – onsite renewable energy technologies, carbon sequestration, purchasing green energy credits, etc. Efforts have subsequently been directed at formulating clear definitions of net zero and carbon neutral and these have provided some degree of clarity and theoretical framing of these notions. The emerging notion of "net positive energy" which, rather than simply being considered an extension of net-zero energy, raises a host of new theoretical and practical issues. This paper is directed at clarifying the notion of net energy positive design with particular focus on what constitutes appropriate boundaries, baseline conditions and associated timeframes.

1. INTRODUCTION

Increasing public and political awareness and concern regarding climate change and global environmental degradation is translating into a greater demand for demonstrated environmental responsibility across all sectors of society. Within the building industry this is manifest in the demand for higher environmental performance requirements of buildings. Moreover, this development is occurring concurrently with a host of other significant shifts: greater interest in systems approaches and associated synergies between strategies, acknowledging relationships between buildings and infrastructure rather than a sole focus on individual buildings, and the recognition and engagement in local/community initiatives as a powerful means to effect positive change.

1.1 *Changing Performance Expectations*

Building environmental performance is, in part, shaped by aspirations. Current performance aspirations themselves have been shaped, again in part, by the widespread use of building environmental assessment methods. In North America, the USGBC's LEED offers "platinum" as its current highest level of performance achievement. Similarly, the UK BREEAM and Australian GreenStar systems offer "Outstanding" and "6-Stars" respectively as their highest performance designations. As such, building developers, designers and other stakeholders within these countries would presumably consider Platinum, Outstanding and 6-Stars as their respective environmental performance aspirations.

Today, however, many North American architectural practices have a wealth of accumulated experience in green design and, indeed, are consistently producing buildings achieving LEED 'Platinum'. This maturing of green building practice has meant that leading-edge 'green' practitioners and clients who have operated at this level are increasingly seeking to push much further than the performance aspirations embedded in current assessment methods. (Cole, 2012) So while the goal of net zero impact is implicit within green building performance and assessment methods, concurrent with the aspiration of achieving high recognition within LEED or BREEAM, the notions of net zero energy and carbon neutrality have become explicit performance goals. Indeed, such aspirations are increasingly embedded in national energy policies with many countries declaring that all new buildings must conform to net zero-energy and/or carbon neutral emission standards by a certain date (Dyrbøl *et al*., 2010; Rovas *et al.*, 2011).

As has been argued in many publications (McDonough and Braungart, 2002; Reed, 2007), green design is primarily directed at "doing less harm" or, more generally, reducing the degenerative consequences of human activity on the health and integrity of ecological systems. This is also embedded in the language and performance criteria in the building environmental assessment methods. Recently, however, the notion of buildings potentially offering a net positive performance is garnering greater interest – driven largely by the increasing literature calling for a fundamental reframing of design. (Birkeland, 2008; du Plessis, 2012; Mang and Reed, 2012) Birkeland (2012), for example, suggests that the necessary "paradigm shift to net positive design will not occur until the legacy of the negative institutional and intellectual infrastructure of [Ecological Sustainable Development] is challenged." (p.165)

This paper is directed at clarifying the notion of net positive design with particular focus on constitutes appropriate boundaries, baseline conditions and timeframes associated with Net Energy Positive Buildings. It begins first by identifying the conceptual underpinnings of net positive, then it summarizes the key definitions and characteristics of Net Zero Energy Buildings before finally exploring the additional considerations, distinctions and implications related to the emerging notion of Net Energy Positive Buildings.

2. NET POSITIVE

Mang and Reed (2012) and du Plessis (2012) present the key attributes of regenerative design and development that promote a co-evolutionary, partnered relationship between humans and natural systems rather than a managerial one and, in doing so, builds, rather than diminishes, social and natural capitals. It is not the building that is 'regenerated' in the same sense as the self-healing and self-organizing attributes of a living system, but by the ways that the act of building can be a catalyst for positive change within the unique 'place' in which it is situated. Within regenerative development, built projects, stakeholder processes and inhabitation are collectively focused on enhancing life in all its manifestations – human, other species, ecological systems – through an enduring responsibility of stewardship. (Cole, 2012) Of relevance to this paper is that the notion of regenerative design raises the promise that buildings can "add value" and be designed and operated to generate more than they need to fulfill their own needs. A key issue in net positive design is, therefore, not simply one of generating more energy but identifying the purpose and designing how the excess resources will be deployed.

Consistent with the fundamental tenets of regenerative design and development, Birkeland presents the idea of net Positive-Development as "physical development that achieves net positive impacts during its life-cycle over pre-development conditions by increasing economic, social *and* ecological capital." Positive Development, she argues, would not only "generate clean energy, air and water"….but would "leave the ecology better than before development." (Birkeland, 2008, p.xv) Embedded within this position is that the renewable energy generated by a building not only offsets that associated with the construction of the building – its embodied energy – but also that of the native landscape prior to development. A similar argument has been presented by Olgyay and Herdt (2004) and Bendewald and Olgyay (2010).

A more prevalent concept of net energy positive design generally relates to:

- Managing energy resources, carbon and other emissions (Torcellini and Crawley, 2006);
- Producing more energy than is needed by a building or system, and exporting this to other systems, i.e., "energy storage management or feeding the extra energy produced to the grid" (Koutroulis, 2006).

The notion of Net-Positive Energy buildings, while following many of the same principles as Net Zero building, introduces several new requirements and possibilities. This paper is primarily interested in the consequences of viewing the role of a building in adding value to a system in which it is part to make it more resilient to future stresses such as "climate change, the change towards a multifunctional and diverse society, the increasing individualization and the observed change in the type of end-users wishes and demands." (Bluyssen, 2010)

3. ENERGY EXCHANGE

Conventional building energy performance derives from the efficiency with which the supply of energy from utilities meet a building's various requirements for comfort provisioning, equipment and various operational processes. It is a one-way flow of energy from the utility to the building that, after fulfilling the various services, finally ends in dissipated heat/carbon emissions. By contrast, the issues explored in this paper involve a much more complex set of potential energy exchanges associated with both Net Zero Energy and Net Energy Positive buildings:

- *Grid-connected:* Two way electrical energy exchange with the utility grid wherein onsite electrical energy is sent to the grid when in excess of needs or drawn from the grid when the onsite electricity generation is insufficient. Grid connection is a necessary and core requirement of net zero energy buildings. Dirks (2010) argues that, '[d]epending on the timing of net demand or net generation and the variability of hourly electricity rates, a net zero-energy facility with "net-metering" may have a net electricity cost or credit.'
- *District heating:* As above, depending on a building's need, thermal energy is drawn from or deposited in a common thermal energy distribution loop.
- *Energy scavenging:* Using waste heat from processes in an adjacent building through dedicated local infrastructure.

The importing of energy to a Net Energy Positive building comes from the electricity and natural gas supply distribution networks. However, the exporting of excess energy to adjacent buildings or those within neighbourhood is in form of 'electricity' (generated from the building's renewable energy sources) and waste heat (heat collected from building services or processes).

3.1 *Net Expectation Benefit*

All the above approaches require a clear link between buildings and infrastructure and associated partnership agreements between agencies/stakeholders engaged in the energy exchange. The most typical agreement relates to the selling and purchasing cost of the energy involved in the exchange.

The notion of "Net Expectation Benefit (NEB)" has been proposed as a key factor in the discussion and definition of net positive energy assessments (Bojić *et al.*, 2011, Kolokotsa *et al.*, 2011). NEB is understood as the generation–consumption difference between the exporting and importing buildings weighted appropriately by the price that energy is sold or purchased, and thereby represents the anticipated monetary gain from the exchange. Here, Kolokotsa *et al.*, (2011) emphasise that the maximization of the Net Energy Benefit is not equivalent to the maximization of the "Net Energy Produced." The former represents the target set by the building operator to "minimize operational costs or, equivalently, maximize return on the energy efficiency measures investment", while the maximization of the Net Energy Produced is considered the "most environmentally-friendly approach since it maximizes the energy produced from the building." (Kolokotsa *et al*., 2011, p. 3077)

3.2 *Net Energy Expectation and Indoor Comfort*

The notion of a Net Positive Energy building is premised on the generation of more energy by a building than is needed to meet its own requirements. The excess energy can be placed into the electrical grid or exported to adjacent buildings to offset their energy requirements. In technical terms, the potential exchange between buildings depends on their relative energy use – how much, what quality (exergy) and when it is required – and their ability to generate energy – again, how much, what quality and when it is produced. The former of these is, to a large extent, related to the expectation for energy services required by buildings which, in the majority of cases is dominated by comfort provisioning. This relationship between energy expectations and comfort requirements associated with the importing and exporting buildings is captured in the notions of "Net Energy Expectation" and 'Comfort index' (Kolokotsa *et al*., 2005, Doukas *et al.,* 2007, Dalamagkidis *et al.,* 2007).

4. NET ZERO ENERGY BUILDINGS

Torcellini *et al*. (2006) argue that "[t]he way the zero energy goal is defined affects the choices designers make to achieve this goal and whether they can claim success" and proceed to offer a clear definition of Net Zero Energy. A central notion within Net Zero Energy, they suggest, is that a building can meet all of its "energy requirements from low-cost, locally available, nonpolluting, renewable sources" or, more specifically a buildings that "generates enough renewable energy on site to equal or exceed its annual energy use." A key part of their definition relate to:

- Distinguishing between renewable energy sources located on the building, on the site or off-site;
- Distinguishing between primary (or source) energy and site (or delivered) energy;
- Distinguishing between electrical and natural gas energy sources and accounting for this distinction through their respective Resource Utilization Factors.[1]

More recently, Sartori *et al*., (2012) have provided further clarifications:

- The inherent interaction between buildings and energy grids means that every country or region faces different challenges with respect to the energy infrastructure in addition to other regional considerations such climate and building traditions;
- The physical boundary for defining net zero energy may be a single building or a cluster of buildings with the latter implying that an overall net zero condition may be attained through the synergy between several buildings which individually may not necessarily be Net ZEB;
- Two-way grids must be available at the physical boundary to define a Net ZEB. A two-way grid - the power grid or local thermal networks, such as district heating/cooling networks - can deliver energy to and also receive energy back from the building(s).

5. NET ENERGY POSITIVE BUILDINGS

The majority of the emerging literature on the notion of Net Energy Positive buildings typically place it alongside Net Zero Energy and consider it to be guided by the same key concepts/principles. (Kolokotsa *et al*., 2011, Wang *et al*., 2009) In this way, a simple definition of a Net Energy Positive building could be one that generates more energy than it uses over a declared period of time, e.g., over a year. Several issues relate to this definition, but those of particular interest to this paper are:

- *Partnering:* As with net zero energy, net positive energy is a systems approach linking the performance of a building with that of others through energy infrastructure that involves a series of negotiations, partnerships and agreements with the associated stakeholders. Certainly a net zero energy building involves an energy and economic exchange with the power utilities, but net positive opens up a host of different exchanges, negotiations and partnerships.
- *Building Types:* Different building types offer different potentials for being Net Zero Energy or Net Energy Positive. Griffith et al. (2007) identify that achieving the ZEB goal on a given building project depends on four characteristics: (1) number of stories; (2) plug and process loads; (3) principal building activity; and (4) location. The issue is one of the extent to which energy demand can be reduced and the ability of the building to accommodate renewable energy systems such as Photovoltaics. Their US-based study indicated that offices need 67% energy savings, warehouses 6%, educational facilities 43%, and retail 44% before PV systems could provide sufficient energy to achieve Net Zero. By extension, greater reductions in energy demand would be required to achieve Net Energy Positive as well as greater potential to accommodate onsite renewable energy systems.

The current emphasis of building energy efficiency or Net Zero Energy relates to the performance and energy/economic benefits accrued by an individual building. Such is the case for the simple definition of Net Energy Positive defined above. However, if a broader framing of net positive is considered, then the benefit gained by the larger system within in which the building sits assumes importance. Since the notion of Net Energy Positive sets buildings as part of a system/neighborhood and explicitly linking them with infrastructure, a number of broader potential benefits emerge, e.g., by exploiting onsite renewable energy sources and exporting surplus energy to the utility grid increases the share of renewable energy within the grid (Sartori *et al*., 2012).

5.1 *Net Energy Positive Buildings & the Grid*

Dirks (2010) examines the significantly different demand profile that a net zero-energy project has compared to that of a conventional building. He argues that the "wide-spread implementation of net zero-energy facilities would significantly change the load profiles that the grid must serve" such that:

- While the absolute energy demand levels would decrease compared to continued development of conventional facilities, the shape of the demand profile (i.e., the extent and timing of peak demand) could change significantly.
- Existing peaks may be flattened and new peaks may be created as a result of the onsite renewable energy generation.

The current number of net Zero Energy buildings is small and the number claiming to be net energy positive is negligible compared to conventional or even low energy buildings. Dirks (2012) raises questions regarding the relationship between the buildings and the utility grids should the number of Net Zero Energy buildings significantly increase. He offers several conclusions of relevance to this paper:

- Without consideration of their impact beyond the building, the widespread adoption of ZEBs will almost certainly lead to suboptimal outcomes when viewed within a broader energy context.
- The value of the energy being produced is as important as the amount in formulating

appropriate design strategies for ZEB buildings.

- Disruptions to the grid associated with a significant level of PV generated electricity from increased ZEBs can be minimized by matching energy loads to the time of peak PV generation.
- Preventing generation peaks of PV systems in ZEBs from flowing back to the grid by directing to some onsite a combination of thermal storage, thermal mass and possibly pre-cooling, phase change materials, chilled water or ice storage and some form of electrical energy storage, "would allow for nearly unlimited penetration of ZEHs."

While many of the above issues are clearly equally applicable to Net Energy Positive buildings, the potential energy exchanges between buildings in addition to the grid connections create a host of new possibilities to minimize peak flows to the grid.

5.2 *Expanding the Range of Energy Services*

Studies examining the potential for buildings to achieve net zero energy (Griffith *et al.,* 2006; Torcellini and Crawley, 2006) suggest that the percentage of commercial floor area able to reach this goal decreases with the increase in number of floors. This derives from the combinations of results from a decrease in daylighting and solar energy potential and an increase plug loads relative to heating and cooling. Goldstein *et al.,* (2010) raise a host of concerns regarding a possible interpretation here that low-rise development less three story buildings is necessary to meet net zero energy goals and argue that:

- It is directly at counter to the goal of reducing transportation energy through high-density development.
- If the definition of Net Zero Energy requires on-site energy generation, this could result in density limits that would create higher transportation and infrastructure emissions than is reduced as a result of improved building performance and onsite energy generation.
- The "on-site" requirement inherent in the zero energy definition could also eliminate the use of rooftop area for personal open space, urban food production, or water collection.

A significant conclusion from Goldstein *et al.'s* paper is that the exclusion of transportation energy from the discussion and framing of net Zero Energy projects, can ultimately lead to sub-optimization in the use of energy at the larger scale. Interestingly, the California Public Utilities Commission (2007) offered a significant shift in the definition of net zero buildings: "Zero Net Energy is herein defined as the implementation of a combination of building energy efficiency design features and on-site clean distributed generation that result in no net purchases from the electricity or gas grid, at the level of a single "project" seeking development entitlements and building code permits. Definition of zero net energy at this scale enables a wider range of technologies to be considered and deployed, including district heating and cooling systems and/or small-scale renewable energy projects that serve more than one home or business." (California Public Utilities Commission, 2007, p.38). Rohloff *et al.,* (2010) suggest that since a "project" within this definition can range from a single building to an entire development, "effectively sets the stage for ZNE "communities" and further deepens the nexus between building and transportation energy use."

It is anticipated that the number of Plug-in Hybrid Electric Vehicles (PHEVs) in California and other locations will increase over the next few decades and that their owners will recharge them at home. Rohloff *et al.,* (2010) suggest that while PHEVs electric charging loads are expected to remain relatively constant over the next 20 years in California, home energy loads will likely to be reduced as energy prices and building energy codes become more stringent. They show that, by 2030, PHEV charging in California will "account for 20% of a typical home's total energy use and will surpass its electricity use." The added charging electricity required PHEVs will need to be met by an increase in the area of onsite photovoltaics and, as such, invariably affect the ability of a home to achieve a net zero energy performance.

6. TIME-FRAME

In net Zero Energy buildings, the time-frame is defined as the period of time over which the building calculation is performed to establish when a balance is met between energy demand and renewable energy supply. This is typically one year but, given year-to-year variations in climate and energy use, a balance may clearly not always be achieved over this time period. Although one year could be selected to designate if a building generates more energy than it uses to be designated as net positive, this would significantly limit the potentials of a net energy positive approach.

Current discussions and definitions of net-zero energy relate only to the operational energy – that is, the onsite generation of energy required to offset a building' annual operating energy (heating, cooling, etc). Hernandez and Kenny (2010) acknowledge that a building's full life cycle would be a more appropriate period for the energy balance, and by implication a discussion of net energy positive. By using the life-cycle, it is possible to include not only the operating energy use, but also the energy embodied in the building materials, construction and demolition and/or technical installations. Within the notion of "life cycle zero energy buildings" the excess energy production is therefore considered to offset all the energy associated with the construction and operation of a building. The expectation, therefore, would be the highest quality of net energy positive system that results from the highest energy performance of the system operation combined with the lowest embodied energy in materials used for system infrastructures associated with the on-site or off-site energy production and transmission services.

7. CONCLUSION

A considerable amount is known about net Zero Energy buildings and, indeed, their definition has been subject to considerable scrutiny and clarification. While net Energy Positive buildings share several of same characteristics, the primary ambition of this paper was to identify those that are unique to a net energy positive system. Three key distinctions are:

1. Rather than a two-way energy exchange between an individual building and the grid and where the benefits are primarily financial and accrued by the building owner, a net positive approach involves a more complex set of energy exchanges and partnerships.

2. Rather than only considering operating energy, the broader spatial framing of net positive potentially captures building energy and transportation energy relationships.

3. Rather than defining the balance period between demand and energy generation over one year, the notion of net positive potentially extends this timeframe to the full-lifecycle and thereby captures operating energy and embodied energy relationships.

Other potential issues/outcomes from the paper are:

- Rather than considering only the generation of more exporting energy versus its importation rate to individual buildings or the grid, net positive energy design should seek the maximization of energy performance in a system-based approach. As such, buildings, landscape, infrastructure and services must be considered as elements of a system/neighborhood collectively as being directed at providing the highest import-export and generation-consumption performance. This extends beyond technical systems and considers inhabitant behaviour and engagement critical to achieving successful performance;

- Rather than focusing solely on the quantity of energy use and exchange, a net positive approach is equally concerned with energy quality, i.e., striving for the lowest waste of energy during the processes of export-import and the lowest transformation of a part of energy to its lower quality forms. To achieve this goal, it will be necessary to improve how, when and where energy is exchanged within the system.
- Improvements will invariably be required in the management and controlling systems associated with energy importation-exportation. The higher demand of energy import in an uncontrolled approach calls for the energy-exporting building/s to provide more infrastructures and utilities to generate more renewable energy, e.g., more PV capacity, wind generators, etc. This in turn, may translate into an increase in a building's embodied energy for the production, installation and maintenances of such systems.

In summary, the paper highlights the importance of striving for 'high-quality net positive' rather than simply responding to higher Net Energy Expectation Benefit demands in a financial-driven approach.

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ENDNOTES

[1] Multiplier applied to the quantity of fuel or energy delivered to a building site, which provides a quantitative estimate of the energy resources consumed in providing that fuel or energy. Variant multipliers account for the burden of processing, transporting, converting, and delivering fuel or energy from the point of extraction to the building site. (http://wiki.ashrae.org/index.php)